90.1 User's Manual

ANSI/ASHRAE/IESNA Standard 90.1 - 2007

Energy Standard for Buildings Except Low-Rise Residential Buildings

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Preface

General Information

This User's Manual provides detailed instruction for the design of commercial and high-rise residential buildings to ensure their compliance with ANSI/ASHRAE/IESNA *Standard 90.1-2007* (referred to in this Manual as *Standard 90.1* or simply the Standard).

In addition, this Manual:

- Encourages the user to apply the principles of effective energy-conserving design when designing buildings and building systems.
- Offers information on the intent and application of *Standard 90.1*.
- Illuminates the Standard through the use of abundant sample calculations and examples.
- Streamlines the process of showing compliance.
- Provides Standard forms to demonstrate compliance.
- Provides useful reference material to assist designers in efficiently completing a successful and complying design.

This Manual also instructs the user in the application of several tools used for compliance with *Standard 90.1*:

- The EnvStd computer program used in conjunction with the Building Envelope Trade-Off compliance method.
- The selection and application of energy simulation programs used in conjunction with the energy cost budget method of compliance.

This Manual is intended to be useful to numerous types of building professionals, including:

- Architects and engineers who must apply the Standard to the design of their buildings.
- Plan examiners and field inspectors who must enforce the Standard in areas where it is adopted as code.
- General and specialty contractors who must construct buildings in compliance with the Standard.
- Product manufacturers, state and local energy offices, policy groups, utilities, and others.

Addenda

Standard 90.1 is a dynamic document undergoing continuous maintenance. Addenda, errata, and interpretations will be issued throughout its life. This edition of the User's Manual is consistent with *Standard 90.1-2007*, and the addenda included therein. The ASHRAE and IESNA boards will approve additional addenda in the future, and the reader should consult the ASHRAE website (www.ashrae.org) or other sources to collect the latest addenda.

When using this Manual to comply with an energy code based on *Standard 90.1*, check whether any addenda have been incorporated in that code, and read those addenda carefully. Also, if one or more of the addenda or criterion of the Standard are not incorporated in an energy code, be careful to apply the recommendations of this Manual appropriately.

Official Interpretations of the Standard

The Standing Standards Project Committee (SSPC) 90.1 provides official interpretations of the Standard upon written request. Address requests for interpretations to the Manager of Standards, ASHRAE, 1791 Tullie Circle, NE, Atlanta, GA, 30329-2305.

Be aware that requests for interpretations are forwarded to the SSPC 90.1. That committee usually assigns the request to a subcommittee, which then reviews it and develops an interpretation. This interpretation is then voted on by the full committee. A common timeframe for a response is six to twelve months.

Standard 90.1 Organization

Numbering System

Standard 90.1 is divided into 12 sections.

Sections 1, 2, 3, 4, and 12 are administrative:

1. Purpose: states the purpose of the Standard.

2. Scope: describes where the Standard applies and does not apply.

3. Definitions, Abbreviations, and Acronyms: provides definitions of terms that are used throughout the Standard and a list of abbreviations, acronyms and symbols.

4. Administration and Enforcement: gives an overview of the Standard's compliance requirements, compliance documentation, materials and equipment labeling, and other administrative requirements.

12. Normative References: lists references and citations used in the Standard.

Sections 5 through 11 are the technical sections of the Standard. Sections 5 through 10 contain the technical requirements for distinct components of the building's design, while § 11 offers an alternative whole building approach to complying with the Standard:

5. Building Envelope: discusses building envelope including fenestration (glazing).

6. Heating, Ventilating, and Air Conditioning: covers HVAC systems, equipment, and controls.

7. Service Water Heating: handles service water heating equipment and systems.

8. Power: applies to building power distribution systems.

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9. Lighting: sets requirements for interior and exterior lighting systems and controls.

10. Other Equipment: talks about permanently wired electric motors.

11. Energy Cost Budget Method: lays out the requirements for developing a computer model for the energy cost budget (ECB) compliance method.

Sections 5 through 11 are further divided into thematic subsections, with each subsection number identifying its use. This numbering system for Sections 5 through 10 is organized as follows:

x.1 General: a general description of a particular section, including the scope and in some instances, some general requirements of the section.

x.2 Compliance Paths: a description of the process of complying with the section of the Standard.

x.3 Simple Buildings or Systems: this only exists for Chapter 6, but a placeholder is held for all the other chapters in the event that a simple compliance approach is developed in the future.

x.4 Mandatory Requirements: the mandatory minimum requirements that all projects must meet under all circumstances.

x.5 Prescriptive Requirements: additional requirements that only apply when the prescriptive method is used to show compliance. Only § 5, § 6, § 7, and § 9 have additional prescriptive requirements.

x.6 Alternative Compliance Path: an alternative approach to compliance. For the Building Envelope chapter a procedure is included that prevents trade-offs between all elements of the building envelope. For the Lighting Chapter, a space-by-space method is provide for determining lighting power allowances.

x.7 Submittals: information that needs to be provided by the designer to the building official, or by the contractor to the designer, to verify that the building complies with the Standard.

x.8 Products: a detailed specification of the requirements.

Section 11 follows a somewhat different numbering system, since this section describes an alternative compliance method rather than requirements for specific components of the building's design.

In addition to the twelve primary sections, the Standard contains a Foreword and six appendices. The Foreword provides a historical perspective on the development of the Standard.

Appendices A through D are normative appendices that are part of the Standard, while Appendices E and F are informative, that are not part of the Standard. A brief description of each Appendix follows.

Appendix A: precalculated U-factors, C-factors, and F-factors for typical construction assemblies and calculation methods for nontypical construction assemblies.

Appendix B: tables providing the 26 building envelope criteria sets for a range of climate conditions.

Appendix C: the methodology for the Building Envelope Trade-Off option in § 5.4.

Appendix D: climate data necessary to determine building envelope and mechanical requirements for various U.S., Canadian, and international locations.

Appendix E: informative references for the convenience of users of the Standard and to acknowledge source documents.

Appendix F: informative listing of approved addenda. The approved addenda define the differences between the 2001 and 2004 versions of *Standard 90.1*.

Appendix G: a procedure for calculating building energy performance ratings.

Table A—*Standard 90.1* and User's Manual Numbering

Item	*Standard 90.1*	*User's Manual*	*Notes*
Major division numbers	Numeric–Sections	Numeric–Chapters	Chapter numbers correspond to section numbers (Chapter 9 and Section 9 are both "Lighting")
Equation, table, and figure numbers	Numeric with section number preceding (Figure 9-3 is the third figure in Section 9)	Alphabetic with chapter number preceding (Figure 9-C is the third figure in Chapter 9)	User's Manual equation, table or figure numbers do not correspond to those of *Standard 90.1* (Table 9-A is not the same as Table 9-1)

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Organization and Use of the User's Manual

In general, the chapters of this User's Manual follow the major sectional organization of the Standard. To aid the user in correlating requirements of the Standard with the explanations in the User's Manual, all major headings in the Manual contain section number references in parentheses. Section numbers are referenced using the symbol §. For example, a discussion of lighting control requirements in this User's Manual begins with the heading, "Lighting Control (§ 9.2.1)." This allows the user to quickly refer to Section 9.2.1 of the Standard, which gives the requirements for lighting control.

Each section of the Standard has a corresponding section in the User's Manual. In addition, Chapters 5 and 7 contain Reference sections to help users understand terms, key concepts, and calculation methods.

Chapters 5, 6, 7, 9, and 11 contain compliance forms to assist in understanding and documenting compliance with the Standard's requirements. Copies of the forms are provided both in printed and electronic form. The electronic versions are contained on the CD distributed with the Manual.

Distinction between References in Standard 90.1 and this Manual

Unless directly footnoted or contained within the text, full citations for documents referred to in this Manual are found in § 12 (Normative References) of *Standard 90.1*.

This Manual uses a distinct terminology and numbering scheme to avoid confusion between references to items within the Standard and this document. These are summarized in Table A.

Data and Analysis Tools

The following is a list of tools that are necessary to apply the Standard. Some of these items, as noted, are only applicable to specific sections of the Standard:

- A current copy of *Standard 90.1-2007* with errata and interpretations.
- Copies of any published addenda to *Standard 90.1*. Several addenda were pending as of the publication date of this Manual.
- A personal computer to run the EnvStd computer program. This program is distributed on CD with this Manual.
- An energy simulation program for the analysis of energy consumption in buildings, if the ECB method of § 11 is to be applied.
- ASHRAE *Handbook—Fundamentals* (2001), which is referenced throughout the Standard.
- ASHRAE *HVAC Systems and Equipment Handbook* (2000) and ASHRAE *Handbook—HVAC Applications* (2003), which are referenced in Chapters 6 and 7 of the Manual.
- ANSI/ASHRAE *Standard 62-2001* (ventilation), which is referenced in § 6.
- In addition to the project plans and specifications, manufacturer's data may be required for lighting, motors, opaque envelope, fenestration, HVAC, control, and water heating systems and equipment.
- A complete set of plans and specifications for the project being reviewed (structural documents are not required).

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Acknowledgments

Architectural Energy Corporation (AEC) prepared this update to the User's Manual under contract to the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). The project was partially funded through a grant from the U. S. Department of Energy.

The 2007 User's Manual builds on the work of those who have already been acknowledged in previous versions. Charles Eley was the project manager and technical editor for the 2007 User's Manual. Zelaikha Akram managed comments, incorporated changes, performed editing, and handled production.

The 2007 Project Monitoring Subcommittee, chaired by Keith Emerson, guided the 2007 User's Manual project and helped reach resolution on issues and problems as they arose. The Project Monitoring Subcommittee also included Michael Lane, Len Sciarra, Allan Fraser, Ross Montgomery, and Mark Hydeman. The 2007 document benefited from the careful review of members of SSPC 90.1 and others. Special acknowledgement is due to Michael Rosenberg, John Hogan and Mick Schwedler. Steve Ferguson was the ASHRAE staff liaison. Jerry White and Mick Schwedler served as SSPC Chairs through this process.

Much of the material in the 2007 manual is carried over from the 1999, 2001, and 2004 versions. Existing and past members of the Standard 90.1 Standing Standards Project Committee (SSPC) wrote the original technical content much of which is still largely intact. Charles Eley wrote the introductory Chapters 1 through 4, Chapter 5 on the building envelope, Chapter 9 on lighting, and Chapter G on the building performance rating method. Steve Taylor and Mark Hydeman of Taylor Engineering wrote Chapter 6 on HVAC and Chapter 7 on service hot water, respectively. Erik Kolderup of AEC wrote chapters 8 and 10. Doug Mahone and Jon McHugh of the Heschong Mahone Group wrote Chapter 11 on the energy cost budget method.

Existing and past members of SSPC 90.1 deserve thanks for their many years of labor. The User's Manual springs from the firm foundation laid by the committee. Literally hundreds of SSPC 90.1 members have contributed to the Standard, and thousands of persons provided useful comments during the many public reviews. It is not possible to acknowledge everyone, but special recognition is due to all of the past SSPC Chairs who worked diligently to establish and maintain 90.1 as the international Standard.

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1. Purpose

Overview

Standard 90.1 provides minimum requirements for the energy-efficient design of buildings and building systems. It applies to all buildings except low-rise residential buildings (low-rise means three habitable floors or less). The Standard is written in building code language and is intended for adoption by national, state/province, and local code jurisdictions. The Standard specifies reasonable design practices and technologies that minimize energy consumption without sacrificing either the comfort or productivity of the occupants. The Standard is broad in scope and the requirements are appropriate for a wide range of building types, climate zones, and for a variety of site conditions. When designing a specific building on a specific site for a specific climate, design issues will undoubtedly have to be addressed that go beyond those considered in developing the Standard.

Enhancements in Standard 90.1-2007

Standard 90.1-2007 is easier to use and more brief than the 1989 version of the Standard. Beginning with *Standard 90.1-1999*, the Standard has been under a program of continuous maintenance. This permits more frequent updates to respond to changing conditions and technologies. The underlying structure of the Standard remains the same and individual sections are amended as needed. These addenda are published by ASHRAE and are available at www.ashrae.org.

The 2007, 2004, 2001, and 1999 versions have a number of enhancements, some of which are described below:

- They are written in code-enforceable language and have unambiguous requirements. The 1989 Standard contained recommendations as well as requirements, which was confusing to many users.
- They are more international. Separate versions are published for metric (SI) units and inch-pound (I-P) units. Criteria are provided for all locations and climates.
- The requirements for the building envelope, lighting and HVAC systems are autonomous and independent of each other, unless the energy cost budget method is used. In the 1989 Standard, these requirements were not independent (e.g., the envelope requirements depended on what the lighting designer did), so that the language was not code enforceable.
- It is more clear how the Standard applies to existing buildings and specifically additions, alterations, and change of use.
- A true prescriptive compliance path (specifying insulation R-values) is offered as one of the options for building envelope compliance.
- Precalculated U-factors for a broad range of common construction assemblies simplify compliance with the building envelope requirements for those using one of the performance options and provide consistency between the Standard's development and implementation.
- Envelope design criteria are specified separately for different classes of wall, roof, and floor construction. For example, the maximum U-factor for a mass wall may be different from the maximum U-factor for a metal-framed or wood-framed wall.
- For fenestration, emphasis is changed from limiting glass area to requiring appropriate performance. There is still a strong incentive, however, to provide an appropriate amount of glass and to provide proper shading.
- The building envelope trade-off option is expanded to permit trade-offs between all building envelope elements (with the 1989 Standard, trade-offs were limited to walls).
- A simple systems option is offered for certain packaged mechanical systems.
- Lighting control requirements are greatly simplified. The complex system of control points in the 1989 Standard is replaced with simple prescriptive requirements.

A number of important changes were included in *Standard 90.1-2004*. Some of the more important changes follow.

- Lighting power limits are significantly lowered to be more consistent with modern lamp/ballast/luminaire technology, as well as the new IESNA requirements.
- Informative Appendix G adds a procedure for building performance ratings. This procedure is appropriate for use with LEED (Leadership in Energy and Environmental Design), utility incentive programs and other programs that encourage buildings to be significantly more energy efficient than *Standard 90.1*.
- Energy efficiency values are added for wall mounted, vertical heat pumps commonly used in relocatable buildings.
- Equipment energy efficiency requirements are updated to be consistent with recent changes to the federal standard.
- Variable frequency drives are required for motors over 10 hp (used to be 25 hp).
- Simulation programs used for the ECB or the building performance rating method must be tested to ASHRAE *Standard 140*.
- The number of building envelope criteria tables and climate zones has changed from 26 to 8.
- The Standard underwent a large-scale reorganization towards the twin goals

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of achieving greater clarity and reducing repetition. The editors worked to present the general requirements in the beginning of the chapter and consolidate highly technical material towards the back. Therefore, each chapter is divided into the following sections:

x.1: General
x.2: Compliance Paths
x.3: Simple Buildings or Systems
x.4: Mandatory Requirements
x.5: Prescriptive Requirements
x.6: Alternative Compliance Path
x.7: Submittals
x.8: Products

A number of important changes were included in *Standard 90.1-2007*. Some of the more important changes follow.

- The building insulation requirements were made more stringent.
- The fenestration requirements were simplified to exclude consideration of orientation and window-wall ratio.
- The cool roof requirements were modified such that alternative criteria is offered when the proposed building has a qualifying cool roof.
- The Appendix A data on metal building roofs was modified to eliminate spacer blocks for through-fastened systems.
- Credit was added for transluscent and louvered overhangs.
- Definitions of the exterior building envelope and the semi-heated exterior envelope were clarified with regard to vestibules.
- The deadband and humidity control requirements were made to apply for data centers.
- The requirement for demand control ventilation was extended to spaces with an occupant density greater than 40 persons per 1,000 ft².
- The fan power requirement was modified along with the allowances for special filtration and other special devices that increase static pressure.
- The HVAC off-hour control requirements were extended to hotel/motel guest rooms.
- The method of allocating additional power for retail display lighting was modified and additional control was required.
- The additional power allowance for VDT work environments was eliminated.

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2. Scope

Authority of Standard 90.1

Standard 90.1 is an ANSI-approved national consensus standard co-sponsored by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Illuminating Engineering Society of North America (IESNA). The Standard is written in code-enforceable language. As a product of consensus and by virtue of the participants in the consensus process, *Standard 90.1* represents the collective views of the manufacturing, design, and construction communities for an appropriate set of minimum requirements for energy-efficient design and construction. Participants in the development and review of the Standard included, among others: professional, technical, and trade organizations; environmental organizations; equipment manufacturers; utility companies; code officials; and design professionals.

Although *Standard 90.1* is not a code, it is intended to be adopted as a code by governmental agencies that are empowered to enact codes through legislative or regulatory processes. These agencies may (and often do) adopt consensus standards published by organizations such as ASHRAE and IESNA. Until *Standard 90.1* is adopted as code, the sponsoring organizations (ASHRAE and IESNA) recommend its voluntary use.

Some agencies may use *Standard 90.1* as the basis for their energy code but make modifications to suit their local conditions. Some requirements may be identical to the Standard while others may be modified. Unless the Standard is adopted or referenced as a whole, care must be taken when using this Manual; certain aspects of the Standard may not apply or may apply differently depending on the modifications made by the adopting agency.

When *Standard 90.1* is adopted and compliance is required, the authority having jurisdiction is responsible for implementing and applying the Standard. Interpretations of the Standard may be requested from ASHRAE at the address provided in the preface to this Manual. However, the ultimate authority for interpretation is the authority having jurisdiction over the building.

Scope of the Standard

The Standard provides minimum energy-efficiency requirements for the design and construction of new buildings and new construction in existing buildings. In particular, it applies to new buildings and their systems, building additions and their systems, and new systems, and equipment in existing buildings.

The scope of the requirements covers the design of the building envelope, lighting systems, HVAC systems, and other energy-using equipment. The Standard applies to the building envelope when it encloses heated and/or cooled space where the heating system has an output capacity greater than or equal to 3.4 Btu/h·ft² (10 W/m²) of floor area or the cooling system has a sensible output capacity greater than or equal to 5 Btu/h·ft² (15 W/m²) of floor area. The Standard also applies to systems and equipment used in conjunction with buildings, including systems for heating, ventilating and air conditioning, service water heating, electric power distribution, electric motors, and lighting.

The Standard does not apply to:

- single-family houses, multi-family structures of three stories or fewer above grade, and manufactured houses (modular or mobile homes);
- buildings that do not use either electricity or fossil fuel; or
- equipment and portions of building systems that use energy primarily to provide for industrial, manufacturing or commercial processes.

Certain other buildings or building components may be exempt by specific notations in the technical sections of the Standard. For example, a manufacturing lab where airflow is supplied to meet the process loads rather than occupant comfort is exempt from the fan power limit requirement. A lab used for research purpose in university is not.

The Standard shall not be used to circumvent any safety, health, or environmental requirements. If there is a conflict between the requirements of this Standard and safety, health, or environmental codes, interpretation should be requested from the local authority having jurisdiction.

Addenda and Interpretations

Standard 90.1 is a dynamic document under continuous maintenance. Addenda, errata, and interpretations will be issued throughout its life. This Manual is consistent with *Standard 90.1-2007*. Appendix F of the Standard provides a detailed list of these addenda. Additional addenda may be approved which could revise the intent of the base document described in this Manual. Designers using this Manual should confirm that an addendum has been adopted by the authority having jurisdiction before incorporating its requirements in the proposed building's design.

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3. Definitions, Abbreviations & Acronyms

Definitions

The Standard includes definitions for the terms listed below. These definitions are not repeated in this Manual, although the index provides a reference to places in the Manual where many of the terms are discussed. Definitions, resources, terms, and calculation methods are presented in the context where they are used in this Manual. When a concept is used more than once in a chapter, it is sometimes included in a Reference section within a chapter.

above-grade wall
access hatch
addition
adopting authority
alteration
annual fuel utilization efficiency (AFUE)
astronomical time switch
attic and other roofs
authority having jurisdiction
automatic
automatic control device
balancing, air system
balancing, hydronic system
ballast
    electronic ballast
    hybrid ballast
    magnetic ballast
baseline building design
baseline building performance
below-grade wall
boiler
    boiler, packaged
branch circuit
budget building design
building
building entrance
building envelope
    building envelope, exterior
    building envelope, semi-exterior
building exit
building grounds lighting
building material
building official
C-factor (thermal conductance)
circuit breaker
class of construction
clerestory
code official
coefficient of performance (COP) – cooling
coefficient of performance (COP), heat pump – heating
conditioned floor area
conditioned space
conductance
continuous insulation (ci)
control
control device
construction
construction documents
cool down
cooled space
cooling degree-day
cooling design temperature
cooling design wet-bulb temperature
dead band
decorative lighting
degree-day
    cooling degree-day base 50°F (10°C), CDD50 (CDD10)
    heating degree-day base 65°F (18°C), HDD65 (HDD18)
demand
design capacity
design conditions
design energy cost
design professional
direct digital control (DDC)
disconnect
distribution system
door
    nonswinging
    swinging
door area
dwelling unit
economizer, air
economizer, water
efficacy (of a lamp)
efficiency
emittance
enclosed space
energy
energy cost budget
energy efficiency ratio (EER)
energy factor (EF)
envelope performance factor
base envelope performance factor
proposed envelope performance factor
equipment
existing building
existing equipment
existing system
exterior building envelope
exterior lighting power allowance
eye adaptation
F-factor
facade area
fan brake horsepower
fan system design conditions
fan system bhp
fan system motor nameplate horsepower
feeder conductors
fenestration
    skylight
    vertical fenestration
fenestration area
fenestration, vertical
fixture
floor, envelope
    mass floor
    steel-joist floor
    wood-framed and other floors
floor area, gross
    gross building envelope floor area
    gross conditioned floor area
    gross lighted floor area
    gross semiheated floor area
flue damper
fossil fuel
fuel
general lighting
generally accepted engineering standard

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grade
gross lighted area (GLA)
gross roof area
gross wall area
heat capacity (HC)
heated space
heat trace
heating design temperature
heating degree-day
heating seasonal performance factor (HSPF)
high frequency electronic ballast
historic
hot water supply boiler
humidistat
HVAC system
indirectly conditioned space
infiltration
installed interior lighting power
integrated part-load value (IPLV)
interior lighting power allowance
isolation devices
joist, steel
kilovolt-ampere (kVA)
kilowatt (kW)
kilowatt-hour (kWh)
labeled
lamp
- compact fluorescent lamp
- fluorescent lamp
- general service lamp
- high-intensity discharge (HID) lamp
- incandescent lamp
- reflector lamp

lighting, decorative
lighting, general
lighting system
lighting power allowance
- interior lighting power allowance
- exterior lighting power allowance

lighting power density (LPD)
low-rise residential
luminaire
manual (non-automatic)
manufacturer
mass floor
mass wall
mean temperature
mechanical heating
mechanical refrigeration
metal building
metal building roof
metal building wall
metering
motor power, rated
nameplate horsepower
nameplate rating
non-automatic
nonrecirculating system
nonrenewable energy
nonresidential
non-standard part-load value (NPLV)
non-swinging door
north-oriented
occupant sensor
opaque
optimum start controls
orientation
outdoor (outside) air
overcurrent
packaged terminal air conditioner (PTAC)
packaged terminal heat pump (PTHP)
party wall
performance rating method
permanently installed
photosensor
plenum
pool
process energy
process load
projection factor (PF)
proposed building performance
proposed design
public facility restroom
pump system power
purchased energy rates
radiant heating system
rated lamp wattage
rated motor power
rated R-value of insulation
rating authority
readily accessible
recirculating system
recooling
record drawings
reflectance
reheating
repair
resistance, electric
reset
residential
roof
- attic and other roofs
- metal building roof
- roof with insulation entirely above deck
- single-rafter roof

roof area, gross
room air conditioner
room cavity ratio (RCR)
seasonal coefficient of performance - cooling ($SCOP_C$)
seasonal coefficient of performance - heating ($SCOP_H$)
seasonal energy efficiency ratio (SEER)
semi-exterior building envelope
semiheated floor area
semiheated space
service
service agency
service equipment
service water heating
setback
setpoint
shading coefficient (SC)
simulation program
single-line diagram
single package vertical air conditioner (SPVAC)
single package vertical heat pump (SPVHP)
single-rafter roof
single-zone system
site-recovered energy
site-solar energy
skylight
skylight well
slab-on-grade floor
- heated slab-on-grade floor

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- unheated slab-on-grade floor
- solar energy source
- solar heat gain coefficient (SHGC)
- space
  - conditioned space
  - cooled space
  - heated space
  - indirectly conditioned space
  - semiheated space
  - unconditioned space
- space-conditioning category
- steel-framed wall
- steel-joist floor
- story
- substantial contact
- swinging door
- system
- system, existing
- tandem wiring
- task lighting
- terminal
- thermal block
- thermal conductance
- thermal resistance (R-value)
- thermostat
- thermostatic control
- tinted
- transformer
  - dry-type transformer
  - liquid-immersed transformer
- U-factor (thermal transmittance)
- unconditioned space
- unenclosed space
- unitary cooling equipment
- unitary heat pump
- variable air volume (VAV) system
- vent damper
- ventilation
- vertical fenestration
- voltage drop
- wall
  - above-grade wall
  - below-grade wall
  - mass wall
  - metal building wall
  - steel-framed wall
  - wood-framed and other walls
- wall area, gross
- warm-up
- water heater
- wood-framed and other walls
- wood-framed and other floors
- zone, HVAC

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Abbreviations & Acronyms

Abbreviations and acronyms used in the Standard and this Manual are listed below:

§	a section in *Standard 90.1-2007*
ac	alternating current
ACH	air changes per hour
AFUE	annual fuel utilization efficiency
AHAM	Association of Home Appliance Manufacturers
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
ASTM	American Society for Testing and Materials
BSR	Board of Standards Review
Btu	British thermal unit
Btu/h	British thermal unit per hour
Btu/ft² ·°F	British thermal unit per square foot degree Fahrenheit
Btu/h ·ft²	British thermal unit per hour square foot
Btu/h ·ft ·°F	British thermal unit per hour lineal foot degree Fahrenheit
Btu/h ·ft² ·°F	British thermal unit per hour square foot degree Fahrenheit
C	Celsius
CDD	cooling degree-day
CDD10	cooling degree-days base 10°C
CDD50	cooling degree-days base 50°F
cfm	cubic feet per minute
ci	continuous insulation
COP	coefficient of performance
CTI	Cooling Tower Institute
DASMA	Door and Access Systems Manufacturers Association
DDC	direct digital control
DOE	U.S. Department of Energy
Ec	combustion efficiency
EER	energy efficiency ratio
EF	energy factor
EnvStd	Envelope System Performance Compliance Program
Et	thermal efficiency
F	Fahrenheit
ft	foot
h	hour
HC	heat capacity
HDD	heating degree-day
HDD18	heating degree-days base 18°C
HDD65	heating degree-days base 65°F
h ·ft² ·°F/Btu	hour square foot degree Fahrenheit per British thermal unit
HID	high-intensity discharge
hp	horsepower
HSPF	heating seasonal performance factor
HVAC	heating, ventilating, and air conditioning
Hz	Hertz

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IESNA	Illuminating Engineering Society of North America
in.	inch
I-P	inch-pound
IPLV	integrated part-load value
K	Kelvin
kg	kilogram
kVA	kilovolt-ampere
kW	kilowatt
kWh	kilowatt-hour
lb	pound
lin	linear
lin ft	linear foot
LPD	lighting power density
L/s	liter per second
m	meter
$m^2 \cdot K/W$	square meter kelvin per watt
MICA	Midwest Insulation Contractors Association
NAECA	National Appliance Energy Conservation Act of 1987
NFPA	National Fire Protection Association
NFRC	National Fenestration Rating Council
PF	projection factor
psig	pounds per square inch gauge
PTAC	packaged terminal air conditioner
PTHP	packaged terminal heat pump
R	R-value (thermal resistance)
R_c	thermal resistance of a material or construction from surface to surface
R_u	total thermal resistance of a material or construction including air film resistances
rpm	revolutions per minute
SC	shading coefficient
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SI	Systeme International d'Unites
SL	standby loss
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
tcf	thousand cubic feet
T_{db}	dry-bulb temperature
T_{wb}	wet-bulb temperature
UL	Underwriters Laboratories Inc.
VAV	variable air volume
VLT	visible light transmittance
W	watt
W/ft^2	watts per square foot
Wh	watthour
W/m^2	watts per square meter
$W/m^2 \cdot °C$	watts per square meter degree Celsius
$W/m \cdot K$	watts per meter Kelvin
$W/m^2 \cdot K$	watts per square meter Kelvin

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4. Administration & Enforcement

Compliance Approaches (§ 4.1)

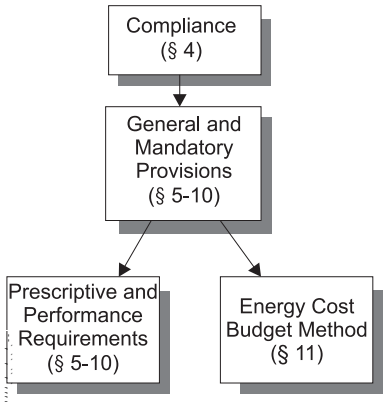

Figure 4-A—The Compliance Path

This chapter addresses administration and enforcement issues, as well as general methods and requirements for demonstrating compliance with the Standard. When the Standard is adopted as a code, the adopting jurisdiction may have some additional requirements. This chapter anticipates some of these requirements, but designers using this Manual should check with the adopting jurisdiction for supplemental information on compliance.

Chapter 4 of the Standard outlines the compliance options and specifies some requirements applicable to all projects. The technical requirements of the Standard are covered in § 5 through § 10, which deal, respectively, with the building envelope, HVAC, service water heating, electrical power, lighting, and electrical motors (other equipment). These technical sections contain general requirements (§ 5.1, § 6.1, § 7.1, § 8.1, § 9.1, and § 10.1), compliance paths (§ 5.2, § 6.2, § 7.2, § 8.2, § 9.2, and § 10.2), simple buildings or systems (§ 5.3, § 6.3, § 7.3, § 8.3, § 9.3, and § 10.3), mandatory requirements (§ 5.4, § 6.4, § 7.4, § 8.4, § 9.4, and § 10.4), prescriptive requirements (§ 5.5, § 6.5, § 7.5, § 8.5, § 9.5, and § 10.5), alternative compliance path (§ 5.6, § 6.6, § 7.6, § 8.6, § 9.6, and § 10.6), submittals (§ 5.7, § 6.7, § 7.7, § 8.7, § 9.7, and § 10.7), and product information (§ 5.8, § 6.8, § 7.8, and § 9.8). The Standard requires that the general and mandatory provisions always be met. However, § 11 of the Standard describes an alternative to the prescriptive and performance requirements: the energy cost budget (ECB) method. The ECB Method is a procedure that enables trade-offs between building systems. For instance, the efficiency of the lighting system might be improved in order to justify fenestration that does not meet the prescriptive envelope requirements. With the ECB Method, compliance can be achieved by first meeting the general and mandatory provisions of each of the technical sections. After that, the estimated annual energy cost of the proposed building must be shown to be less than the annual energy cost of a standard building that exactly complies with the prescriptive requirements.

New Buildings (§ 4.1.1.1)

The main focus of the Standard is on new buildings. Every new building project is different: each building has its own site that presents unique opportunities and challenges; each building owner or user has different requirements; and climate and microclimate conditions can vary significantly among projects. Architects and engineers need flexibility in order to design buildings that address these diverse requirements. The Standard provides this flexibility in a number of ways. Each of the technical sections has multiple compliance paths. To use the building envelope section as an example, designers can choose a prescriptive method that requires that insulation be installed with a minimum R-value. Alternatively, a component performance method allows the designer to show compliance with the thermal performance (U-factor) of construction assemblies for each component. Finally, a building envelope trade-off option is provided that permits trade-offs between building envelope components. If more flexibility is needed, the energy cost budget method is available. The lighting and HVAC sections also offer flexibility and exceptions for special cases. The specifics of the various compliance options are presented in each of the technical chapters in this Manual.

Existing Buildings (§ 4.1.2, § 4.1.1.3, and § 4.1.1.4)

The Standard also applies to certain work in existing buildings. The requirements are triggered when new construction is proposed, such as an addition, or when unconditioned space is converted to conditioned space (that is, heating and/or cooling is added for the first time). The Standard applies to additions and alterations much as it does to new buildings: the Mandatory Provisions must *always* be met; after that, multiple compliance options may apply. In existing buildings, however, there is a general exception to the Standard whenever compliance with the requirements can be shown to cause an increase in the building's annual energy use. Compliance details are discussed below for additions, alterations, and changes in conditioned space.

Additions (§ 4.1.1.2)

An addition is a new wing or new floor that extends or increases the building floor area or height of a building outside the envelope of the existing building. The Standard applies to the addition but does not require any changes or upgrades to the existing building. As is the case with new buildings, the Mandatory Provisions must be complied with; also, the addition must either comply with the prescriptive or performance requirements of all the

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applicable technical sections or with the energy cost budget (ECB) method.

The simplest compliance method for additions is to treat the addition as if it were its own separate building. The Mandatory Provisions of the building envelope, lighting, and HVAC sections apply to the addition, and after that, the addition must meet either the prescriptive/performance requirements of each of the technical sections or comply using the ECB Method.

A second option is to make trade-offs between the addition and improvements to the existing building so that the annual energy cost of the existing building plus the proposed addition is less than the existing building plus an addition that exactly meets the prescriptive requirements (see Exception to 4.2.1.2). This approach can only be applied using the ECB Method. For instance, it may be desirable that the exterior envelope of the addition matches the existing building facades. While the envelope might not meet the Standard, other systems such as lighting might be improved to make up for it.

When heating and/or cooling for the addition is provided by existing HVAC equipment or systems, the existing equipment and systems do not have to be upgraded to comply with the Standard. However, it is necessary that new HVAC equipment or systems comply. Likewise, if service hot water for the addition is provided by an existing hot water system, it is not necessary to upgrade the existing system. Table 4-A provides some examples of how the Standard applies to existing HVAC equipment and systems that are being extended to serve an addition.

Alterations (§ 4.1.1.3)

The Standard applies to certain aspects of new construction in existing buildings. In general, the Standard only applies to new building systems and equipment (e.g., building envelope, heating, ventilation, air-conditioning, service water heating, power, lighting, and electric motors). The Standard does not apply to building systems or equipment that are not being altered or repaired unless there is a change in space conditioning (see § 4.1.2.3). Alterations may comply with the Standard in two ways:

- The first approach is to show that each system, piece of equipment, or component that is being replaced complies individually with the applicable requirements of § 5, § 6, § 7, § 8, § 9, and § 10. With this approach, each component that is being replaced must separately comply with the Standard. There can be no trade-offs among components.
- The second approach (described in Exception to 4.2.1.2) is to evaluate the alteration as a whole and show that the annual energy consumption of the proposed alteration does not exceed the annual energy consumption of a substantially identical alteration that exactly meets all the prescriptive requirements. This approach permits trade-offs between components and equipment as long as the proposed alteration performs as well as if it complied exactly with the prescriptive requirements. The proposed alteration must still comply with the Mandatory Provisions, and this approach only applies to alterations that replace or modify more than one system. For instance, this approach cannot be applied when just a water heater is being replaced. When this approach is used, the calculations and performance analysis must be verified by an architect or engineer licensed to practice in the jurisdiction.

The trade-off approach for alterations can only be applied if there is no change in the type of energy used (e.g., gas, oil, electricity, etc.). This is mainly an issue for heating systems. If the existing heating system has gas heat, then the alteration must also have gas heat in order to use the tradeoff approach.

Historic buildings are exempt from the requirements of the Standard for building alterations (see Exception (a) to 4.2.1.3). In order to qualify for the exemption, the historic building must be designated as historically significant by the authority having jurisdiction or listed (or eligible for listing) in the National Register of Historic Places. The National Register is

Table 4-A—Applying the Standard to Existing HVAC Equipment and Systems Being Extended to Serve an Addition

Situation	*Application of Standard*
An existing central plant will provide hot and cold water to new fan coils in a building addition.	The Standard applies to the fan coils and controls in the addition but not to the existing central plant.
A variable air volume (VAV) air handler in the existing building will provide cool air and outdoor air ventilation to an addition.	The Standard applies to the VAV boxes and controls in the addition but not to the existing air handler or the central plant that serves it.
An addition is served by its own single-zone HVAC system.	The Standard applies to the HVAC system and controls in the same way that it applies to new construction.

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administered by the National Park Service, which is part of the U.S. Department of the Interior.

Several important exceptions and particulars apply specifically to the alteration of existing buildings. These are discussed and organized by building system.

Building Envelope

The following types of building envelope alterations are exempt from compliance with the Standard, provided they do not increase the energy usage of the building:

a. Installing storm windows over existing glazing. This can only improve the performance of the building envelope by reducing both the U-factor and the solar heat gain coefficient (SHGC).

b. Replacing broken or damaged glazing in an existing sash and frame, provided that the U-factor and SHGC of the replacement glass are equal to or lower than those of the original glass. In-kind replacement glazing will always satisfy this exception. However, see (g) if glass and sash are being replaced in an existing frame, or if glass, sash, and frame are being replaced.

c. Altering roofs, ceilings, walls or floors that have cavities, as long as the cavity is filled with insulation having an insulating value of at least R-3.0 per inch (R-0.02/mm). Filling the cavity with insulation is easy to achieve and cost-effective.

d. Altering walls and floors that have no framing cavities. Insulating these types of construction presents practical difficulties and may not be cost-effective unless special circumstances exist.

e. Replacing a roof membrane, as long as neither the roof sheathing nor the existing insulation is exposed. However, if the roof is stripped down to the level of the sheathing or insulation, then the roof must be insulated to the requirements of the Standard (unless the insulation is located below the sheathing).

f. Replacing exterior doors does not trigger the requirement for a vestibule or revolving door. However, if a vestibule or revolving door exists, it may not be removed.

g. Replacing existing fenestration (windows, plastic panels, glass blocks, glass doors, or skylights), as long as the area of fenestration that is being replaced is less than 25% of the total fenestration area of the existing building. Also, the U-factor and SHGC of the replacement fenestration must be equal to or less than those of the original fenestration. If the replacement fenestration area exceeds 25%, then the replacement fenestration that is installed must meet the requirements of the Standard.

HVAC Equipment

HVAC equipment that is a direct replacement of existing equipment must meet the Standard's efficiency requirements. This applies, but is not limited to, air conditioners and condensing units, heat pumps, water chilling packages, packaged terminal and room air conditioners and heat pumps, furnaces, duct furnaces, unit heaters, boilers, and cooling towers. This will generally be self-regulating since much of the HVAC equipment covered by the Standard is also covered by the National Appliance Energy Conservation Act (NAECA), which has established minimum energy-efficiency requirements consistent with those of the Standard. Chapter 6 discusses the types and sizes of equipment that are covered by NAECA.

There are a number of important instances when the Standard does not apply to replacement HVAC equipment. In particular, the Standard does not apply:

a. When equipment is repaired but not replaced. As long as parts within the unit are being replaced but not the unit as a whole, the Standard does not apply. However, the modifications may not increase energy use. For instance, if a condenser coil is replaced, the new coil must have the same heat transfer performance (tube and fin spacing, fin type) as the coil being replaced.

b. When the replacement of existing equipment with complying equipment requires extensive revisions to other systems, equipment, or elements of the building and where the replacement equipment is a like-for-like replacement. For example, if extensive modifications to a building or heating distribution system are required to accommodate replacement of an existing boiler with a new boiler that complies with the Standard, compliance is not required.

c. When the refrigerant in existing equipment is changed. This will often reduce efficiency but may be required in order to reduce the ozone-depletion potential of the equipment or to meet other regulatory requirements.

d. When existing equipment is relocated. For instance, the Standard does not apply when an existing hydronic heat pump is moved to another location within the building or to another existing building.

Service Water Heating

When water heaters are replaced in existing buildings, the replacement equipment must meet the requirements of the Standard. Most water heaters are also covered by NAECA, which has efficiency requirements consistent with those of the Standard. However, minor alterations to a water heating system, such as extending the pipes to new fixtures or installing

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valves do not trigger an upgrade to the service water heating system.

Electric Power
If modifications are made to the electric power distribution system, the Standard's requirements apply to the components that are being modified or replaced but not to the entire system. It is important to review the requirements of § 8, as the Standard's requirements for building electrical systems are quite limited in scope.

Lighting
The lighting power density requirements of the Standard apply to new lighting systems in any space in an existing building. A new lighting system is one that replaces 50% or more of the existing luminaires in any building space. A renovation of a space that replaces less than 50% of the existing luminaires in that space is not required to comply with the Standard, unless the renovation increases installed lighting power.

New lighting control devices that are direct replacements of existing control devices must meet some of the requirements of the Standard. In particular, the new device may not control more than 2,500 ft² (232 m²) in spaces less than 10,000 ft² (929 m²). For spaces larger than 10,000 ft² (929 m²), the device may not control more than 10,000 ft² (929 m²). In addition, each replacement control must be readily accessible and located so that occupants can see the controlled lighting.

Other Equipment
When electric motors are replaced, they must meet the requirements of § 10. However, the Standard does not apply when existing motors are relocated. The efficiency requirements in § 10 are part of federal law in the United States and enforcement should happen at the time of manufacture or importation. Therefore, all motors purchased in the United States should already comply with the requirements of the Standard.

Changes in Space Conditioning (§ 4.1.1.5)

The Standard applies in its entirety when previously unconditioned space or semiheated space is converted to conditioned space (either heated or cooled). This includes building envelope, heating, ventilating, air-conditioning, service water heating, power, lighting, and other systems and equipment that serve the space that is being heated and/or cooled. Note that if a space is already heated (i.e., conditioned), then adding mechanical cooling does not trigger this requirement because the space is already considered a conditioned space.

Administrative Requirements (§ 4.1.2)

All administrative requirements related to building permits, enforcement procedures, interpretations, claims of exemption, and rights of appeal are defined by the authority having jurisdiction.

Alternative Materials, Construction Methods, or Design (§ 4.1.3)

There will be situations where equipment, materials, design, or products proposed for installation in a building are not specifically addressed by the Standard. This may be particularly true with new materials or innovative products. It is not the intent of the Standard to prevent the use of such new products, designs, or construction technologies so long as their installation is consistent with the requirements of other codes as they pertain to health and life safety.

Compliance Documentation (§ 4.2.2)

Documentation of compliance consists of all materials including plans, specifications, calculations, diagrams, reports, and other data that have been submitted in support of a permit application and subsequently approved by a code enforcement official. All such documentation must be in sufficient detail to permit a determination of compliance by the building official. The building official may request additional information if required to verify compliance.

Compliance forms and worksheets are provided with this Manual and are intended to facilitate the process of complying with the Standard. These forms serve a number of functions.

- They help a permit applicant and designer know what information needs to be included on the plans.
- They provide a structure and order for the necessary calculations. The forms allow information to be presented in a consistent manner, which is a benefit to both the permit applicant and the building official.
- They provide a roadmap showing the building official where to look for the necessary information on the plans and specifications.
- They provide a checklist for the building official to help structure the plan check process.
- They promote communication between the plans examiner and the field inspector.
- They provide a checklist for the inspector.

Labeling of Materials and Equipment (§ 4.2.3)

The overall performance of fenestration products, insulation material, water heaters, and HVAC equipment is determined through laboratory tests and

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calculations that cannot easily be performed in the field. For this reason, labeling is frequently required so that construction managers, field inspectors, design professionals, and general contractors can verify that the products, materials, and equipment being installed comply with the Standard. The intent of these labeling requirements is to make it easier to do field verification and administration. The Standard requires labeling of the following products:

- *Fenestration*: The U-factor, solar heat gain coefficient (SHGC), and air leakage rate for all manufactured fenestration products must be identified on a permanent nameplate installed on the product by the manufacturer. This nameplate will also generally include the serial number and information about the standards to which the unit has been tested. Most manufacturers install this nameplate on the frame of the unit. Alternatively, when fenestration products do not have a nameplate, the installer or supplier of the fenestration must provide a signed and dated certification for the installed fenestration listing the U-factor, SHGC, and air leakage rate.
- *Doors:* The U-factor and the air leakage rate for all manufactured doors used in the exterior or semi-exterior envelope must be identified on a permanent nameplate installed on the product by the manufacturer. As with fenestration products, this nameplate is generally located on the side of the door or the door frame and additionally includes information about the door's fire rating. Alternatively, when doors do not have a nameplate, the installer or supplier must provide a signed and dated certification for the installed doors listing the U-factor and the air leakage rate.
- *Insulation:* The rated R-value must be clearly indicated by an identification mark applied by the manufacturer to each piece of building envelope insulation. Alternatively, when insulation does not have an identification mark, the supplier or installer must provide a signed and dated certificate listing the type of insulation, the manufacturer, the rated R-value, and, where appropriate, the initial installed thickness, the settled thickness, and the coverage area. The certificate is most common for blown-in insulation products.
- *Mechanical Equipment*: Mechanical equipment that is not covered by the National Appliance Energy Conservation Act (NAECA) of 1987 must carry a permanent label installed by the manufacturer stating that the equipment complies with the requirements of ANSI/ASHRAE/IESNA *Standard 90.1*. NAECA-regulated equipment must also be labeled, but the labeling requirements are addressed by the federal act, not by *Standard 90.1*.
- Packaged Terminal Air Conditioners: The replacement of packaged terminal air conditioners in some existing wall openings sometimes presents difficulties if the original wall opening is small. Packaged terminal air conditioners that may be used in these situations are subject to specific labeling requirements. Packaged terminal air conditioners and heat pumps with sleeve sizes less than 16 in. × 42 in. (0.41 m × 1.05 m) must be factory labeled as follows: "Manufactured for replacement applications only: not to be installed in new construction projects."

Table 4-B—Field Inspections

Discipline	*Inspection phase*	*When inspected*	*Example of things to check*
Envelope	Foundation	Before backfill of foundation walls	Slab edge insulation
	Rough-in	Before interior finish materials are installed, but after fenestration and doors are in place	Wall, roof and floor insulation Sealing and infiltration control Window and skylight areas Fenestration products match plans
	Final	Before occupancy	High reflectance, high emittance roof surfaces
Electrical	Foundation	Before cover-up	Transformer
	Rough-in	Before building insulation is installed	Lighting controls are properly located Circuits are acceptable
	Final	Before occupancy	Current fixtures are in place
Mechanical	Foundation	Not applicable	Not applicable
	Rough-in	Before interior finish materials are installed	Ductwork and pipe insulation
	Final	Before occupancy	Equipment meets efficiency requirements

Inspections (§ 4.2.4)

The Standard requires that construction work be available for field inspections. For smaller buildings, inspections are typically made during certain phases in the construction process, for example, during foundation, rough-in, and final. Larger and more complex buildings will often have many more inspections at additional times during the construction process. Table 4-B

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has examples of work that is subject to field inspection.

The Standard is specific about certain details. Work that is critical to compliance with the Standard must remain accessible and exposed for inspection until approved in accordance with procedures specified by the building official. Items for inspection include at least the following:

- Wall insulation, roof/ceiling insulation and vapor retarders must be available for inspection after installation but before concealment.
- Slab/foundation insulation must be available for inspection after installation but before concealment.
- Fenestration products must be available for inspection after installation.
- Mechanical systems, equipment, and insulation must be available for inspection after installation but before concealment.
- Electrical equipment and systems must be available for inspection after installation but before concealment.

Referenced Standards (§ 4.1.6)

The standards referenced in § 12 are considered to be "normative" references and as such are part of the Standard to the extent of the reference. Where differences occur between the provisions of the Standard and referenced standards, the provisions of the Standard apply.

Normative Appendices (§ 4.1.7)

The normative appendices to the Standard are integral parts of the Standard. They are included in the appendix as a matter of convenience. Appendix A contains precalculated building envelope performance factors that can be used for compliance purposes as well as descriptions of acceptable methods for calculating U-factors. Appendix B contains the building envelope requirements for all locations throughout the world and Appendix D contains climate data for locations throughout the world. When the Standard is adopted for use as a code in a particular jurisdiction, usually only one page from Appendix B and a few data points from Appendix D are relevant (except in large jurisdictions, where multiple pages may be relevant). Appendix C contains the procedures for making building envelope trade-offs, which are incorporated in computer software distributed with this Manual. Appendix G describes the building performance rating method.

Informative Appendices (§ 4.1.8)

The Standard also contains two informative appendices. One appendix provides references and acknowledges source documents. This informative appendix does not contain requirements that are a part of the Standard. The second appendix describes the addenda from *Standard 90.1-2001* that has been incorporated in 90.1-2007.

Validity (§ 4.1.4)

The Standard states, "If any term, part, provision, section, paragraph, subdivision, table, chart, or referenced standard of this Standard shall be held unconstitutional, invalid, or ineffective in whole or in part, such determination shall not be deemed to invalidate any remaining terms, parts, provisions, sections, paragraphs, subdivisions, tables, or charts of this Standard." This language is generally used within codes and provides that if one particular part of the code is challenged and subsequently removed, that action does not invalidate the remainder of the code's requirements.

Operation and Maintenance Manuals (§ 4.2.2.3)

Optimum energy efficiency requires that the building and the equipment installed in the building be operated and maintained in accordance with the design intent. The Standard requires that operating and maintenance information be provided to the building owner. This information is specified in the HVAC and electric power technical sections (see in particular § 6.7.2.2 and § 8.7.2 of the Standard).

Conflicts with Other Laws (§ 4.1.5)

The requirements of this Standard do not nullify any provisions of local, state, or federal law. If there is a conflict between a requirement of this Standard and another building code requirement or law, the authority having jurisdiction determines precedence.

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The Compliance and Enforcement Process

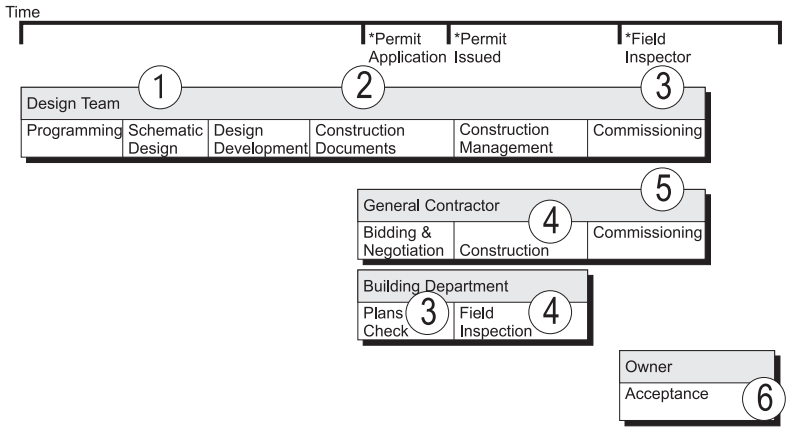

Figure 4-B—The Building Design and Construction Process

Although the compliance and enforcement process may vary somewhat with each adopting jurisdiction, the enforcement authority is generally the building department or other agency that has responsibility for approving and issuing building permits. When noncompliance or omissions are discovered during the plan review process, the building official may issue a correction list and require the plans and applications to be revised to bring them into compliance prior to issuing a building permit. In addition, the building official has the authority to stop work during construction when a code violation is discovered.

The local building department has jurisdiction for determining the administrative requirements relating to permit applications. They are also the final word on interpretations, claims of exemption, and rights of appeal. From time to time, ASHRAE will issue interpretations clarifying the intent of the Standard. The local building department may take these under consideration, but the local building department still has the final word.

To achieve the greatest degree of compliance and to facilitate the enforcement process, the Standard should be considered at each phase of the design and construction process (see Figure 4-B).

1. At the design phase, designers must understand both the requirements and the underlying intent of the Standard. The technical sections of this Manual provide information that designers need to understand how the Standard applies both to individual building systems and to the integrated building design.

2. At permit application, the design team must make sure that the construction documents submitted with the permit application contain all the information that the building official will need to verify that the building satisfies the requirements of the Standard. (This Manual provides compliance forms and worksheets to help ensure that all the required information is submitted.)

3. During plan review, the building official must verify that the proposed work satisfies the requirements of the Standard and that the plans (not just the forms) describe a building that complies with the Standard. The building official may also make a list of items to be verified later by the field inspector.

4. During construction, the contractor must carefully follow the approved plans and specifications. The design professional should carefully check the documentation and shop drawings that demonstrate compliance and should observe the construction in progress to see that compliance is achieved. The building official must verify that the building is constructed according to the plans and specifications.

5. After completion of construction, the contractor and/or designer should provide information to the building operators on maintenance and operation of the building and its equipment. Although only minimal completion and commissioning is required by the Standard, most energy efficiency experts agree that full commissioning is important for proper building operation and management.

6. After occupancy, the building and its systems must be correctly operated and properly maintained. In addition, building users should be advised of their opportunities and responsibilities for saving energy (for example, by turning off lights when possible).

Effective compliance and enforcement requires coordination and communication among all parties involved in the building project.

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Example 4-A—Compliance Procedures, ECB Method

Q

A designer of a large shopping mall wishes to demonstrate compliance using the energy cost budget (ECB) method of § 11. The proposed design, which specifies HVAC equipment that does not meet the efficiency equipment requirements of § 6, can be shown to have a lower annual energy cost than the budget building. Does this design comply with the Standard?

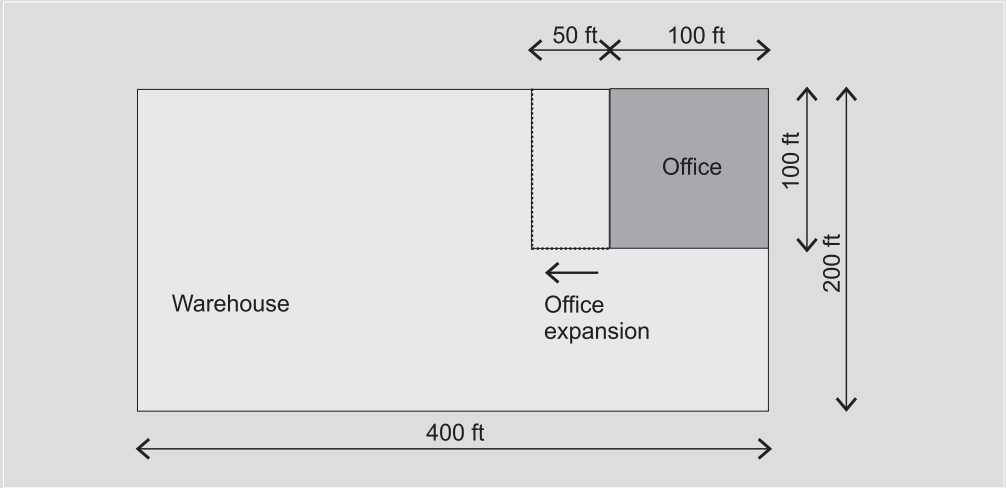
A

No. Using the ECB Method does not release the designer from any of the Mandatory Provisions. The HVAC equipment must meet the minimum efficiency requirements of § 6. To demonstrate compliance using the ECB Method, the designer must also show that the proposed project meets the Mandatory Provisions of all the technical sections of the Standard.

Example 4-B—Expansion of Office into Warehouse

Q

An existing warehouse measures 400 ft × 200 ft. The warehouse is unconditioned, but administrative offices are located in a 100 ft × 100 ft corner. The offices are served by a single-zone rooftop packaged HVAC system that provides both heating and cooling. The owner wants to expand the administrative offices into the warehouse. The new office space will convert an area that measures 100 ft × 50 ft from unconditioned to conditioned space. The existing HVAC system has sufficient capacity to serve the additional space. However, new ductwork and supply registers will need to be installed to serve the additional space. Does the Standard apply to this construction project?



A

The Standard applies to the 100 ft × 50 ft space that is being converted from unconditioned to conditioned space. However, the Standard does not apply to the existing office or the existing warehouse space. The new lighting system installed in the office addition must meet the requirements of § 9. The walls that separate the office addition from the unconditioned warehouse must be insulated to the requirements for semiheated spaces. The exterior wall and roof are exterior building envelope components and must meet the requirements for nonresidential spaces. The existing HVAC system does not need to be modified, but the ductwork extensions must be insulated to the requirements of § 6.

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5. Building Envelope

General Information (§ 5.1)

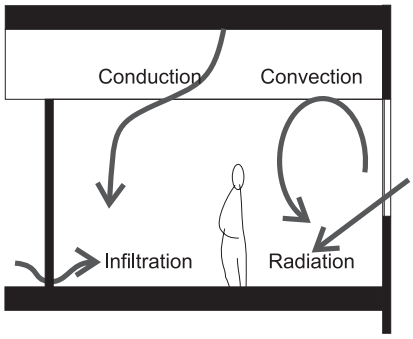

Figure 5-A—External Loads

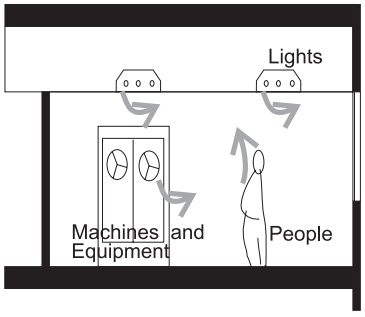

Figure 5-B—Internal Loads

General Design Considerations

The building envelope is one of the most important factors in designing energy-efficient buildings. While the envelope does not directly use energy, its design strongly affects heating and cooling loads (HVAC energy). For example, insulation affects the temperature of inside surfaces, which can have a significant effect on comfort. Also, glazing can introduce daylighting into the space, reducing the need for electric lighting.

Integrated design considers multiple elements—the building envelope, the HVAC system, and the lighting system—as a whole. It recognizes that changing one can affect the other two. For instance, investments in insulation or energy-efficient windows can result in smaller HVAC systems, which will help pay for the better envelope.

The envelope design must take into consideration both external loads and internal loads, as well as daylighting benefits. External loads include solar gains, conduction losses across envelope surfaces, and infiltration, while internal loads include heat gain from lights, equipment, and people. (The Reference section at the end of this chapter reviews the concepts of external and internal loads in more detail.) The temperature at which losses through the building envelope balance internal heat gains is the building's balance point temperature. The balance point temperature depends on the magnitude of internal gains, the rate of heat loss through the building envelope, and the quantity of outdoor air brought into the building through the HVAC system.

The balance point varies by building use and is different for occupied and unoccupied hours. For example, a laundry or a commercial kitchen will likely have a lower balance point temperature because of high internal loads. By contrast, a high-rise residential building will have relatively low internal loads and a higher balance point. A typical office building has a low balance point temperature during daytime occupied periods and a higher balance point temperature during unoccupied evening hours. As a result, the office may require cooling during the day and heating at night and for early morning warm-up.

The ideal building envelope would control exterior loads in response to coincident internal loads to achieve a thermal balance for each set of conditions. When the building is in a cooling mode, solar gains should be reduced while still admitting daylighting, and outdoor air

Inch-Pound and Metric (SI) Units

The Standard is available in two versions. One uses inch-pound (I-P) units, which are commonly used in the United States. The other version uses metric (SI) units, which are used in Canada and most of the rest of the world. Most of the examples and tables in this chapter use inch-pound units; however, where it is convenient, dual units are given in the text. The SI units follow the I-P units in parenthesis. In addition, the following table may be used to convert I-P units to SI units.

	I-P Units		**SI Units**
U-factor	Btu/h·ft²·°F	× 5.6732	= W/m²·°C
R-factor	h·ft²·°F/Btu	× 0.1762	= m²·°C/W
Length	ft	× 0.3048	= m
	in	× 25.4	= mm
HC	Btu/ft²·°F	× 20.441	= kJ/m²·°C
Weight/Area	lb/ft²	× 4.8806	= kG/m²
Area	ft²	× 0.0929	= m²
Power	Btu/h	× 0.2928	= W
Density	lb/ft³	× 16.018	= kG/m²
Power Density	W/ft²	× 10.7639	= W/m²
	Btu/h·ft²	× 3.1506	= W/m²
Airflow	cfm	× 0.4719	= l/s
Conductivity	Btu·in/h·ft²·°F	× 0.1441	= W/m·°C

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should be introduced if outdoor conditions are suitable. Outdoor air could also be introduced during evening hours to cool thermal mass in preparation for the next day's loads. If the building is in a heating mode during the day, solar gains should be increased and heat losses due to both conduction and infiltration should be reduced.

The desired thermal balance may be achieved through the design and selection of building envelope components such as insulation, thermal mass, caulking, and weather-stripping, but in most buildings, the most significant element of the envelope design is the fenestration. The fenestration design has a considerable impact on solar gains, heat loss and infiltration, and, in combination with interior space planning, determines the potential for introducing daylighting into the building. Finding the right fenestration design and optimizing levels of insulation for each climate and internal load condition is a complicated process.

The Standard sets minimum levels of thermal performance for all components of the building envelope and limits solar gain through fenestration, based on climate zone, type of space and occupancy.

Scope (§ 5.1.1)

The Standard applies to envelope components that enclose conditioned space or semiheated space. The building envelope requirements are more stringent for conditioned space than they are for semiheated space. The building envelope requirements do not apply to unconditioned space. Conditioned space is space that has a heating and/or cooling system of sufficient size to maintain temperatures suitable for human comfort. For simplicity of compliance, the definition of conditioned space is expressed in terms of installed heating and/or cooling equipment capacity per square foot of floor area. For cooling, the threshold is 5.0 Btu/h-ft² (16 W/m²) and for heating the threshold depends on the climate zone of the building location (as indicated in Table 3.1). Semiheated space has a heating system with a capacity greater than 3.4 Btu/h ·ft² (10 W/m²) of floor area but smaller than that needed to qualify for conditioned space (as shown in Table 3.1). Unconditioned space is not cooled and has a heating system smaller than 3.4 Btu/h ·ft² (10 W/m²). Warehouses and storage facilities may be unconditioned or semiheated, depending on the installed capacity of the heating system.

Designating a space as conditioned, semiheated, or unconditioned affects whether the envelope requirements apply and how much insulation must be installed. For shell or speculative buildings that do not have a heating system shown on the plans, all spaces must be considered conditioned in climates zones 3 through 8 unless approval is granted by the building official to designate the space as semiheated or unconditioned.

Building envelopes consist of opaque components and fenestration components. Opaque envelope components include walls, roofs, floors, slabs-on-grade, below-grade walls, and opaque doors. Fenestration envelope components include windows, skylights, and doors that are more than one-half glazed.

Envelope Component Types

An envelope component can be either exterior or semi-exterior.

- Exterior envelope components separate conditioned space from outdoor conditions, including ventilated crawl spaces and attics.
- Semi-exterior envelope components separate conditioned space from unconditioned space or from semiheated space. Semi-exterior envelope components also separate semiheated space from exterior (outdoor) conditions or from unconditioned space.

Being able to identify exterior and semi-exterior envelope components is essential for the proper use of the Standard. The requirements for semiheated spaces apply to semi-exterior envelope components, while the requirements for nonresidential or residential spaces apply to exterior envelope components. The requirements for exterior envelope components are more stringent than those for semi-exterior envelope components.

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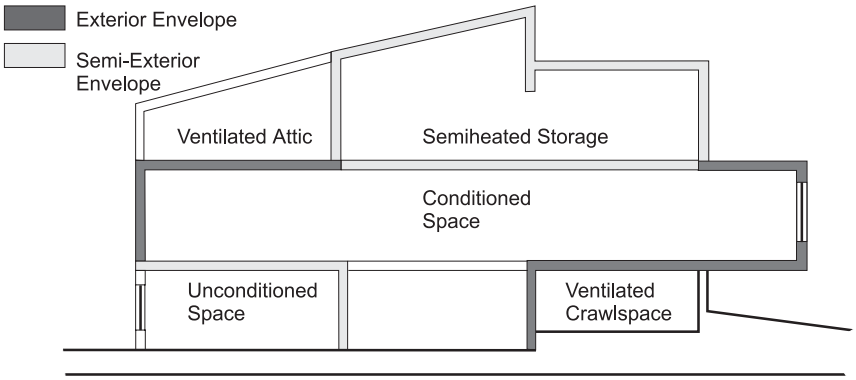

Figure 5-C—Scope of Envelope Requirements

Figure 5-C shows a section through a building. This figure shows many types of spaces in order to illustrate the distinctions between exterior and semi-exterior envelope components. The middle floor and part of the basement are conditioned. The upstairs is semiheated, and a portion of the basement is unconditioned. In addition, the building has a ventilated crawl space and a ventilated attic. In this figure, exterior envelope components are shaded dark and semi-exterior envelope components are lightly shaded.

The Standard does not apply to the unshaded envelope components, since these are neither exterior nor semi-exterior. Notice that all the envelope components surrounding the semiheated space are semi-exterior. The exterior envelope components separate the conditioned space from the outdoors or from the ventilated attic or crawl space. Envelope components that separate conditioned space from unconditioned space are also semi-exterior.

Process Energy Use

The Standard does not apply to equipment and portions of building systems that use energy primarily to provide for industrial, manufacturing or commercial processes (§ 2.3e). For example, the Standard does not apply to refrigerated warehouses that are cooled to maintain the quality of the goods stored in the warehouse. Other warehouses that have minimal heating capability for freeze protection might qualify as semiheated spaces.

Shell Buildings

Shell buildings are another special case. The building shell is constructed before it is known how the building will be used. The HVAC and lighting systems are installed later, at the time of tenant improvements. Shell buildings have consistently created code enforcement problems, as tenants assume that the building envelope already complies with the code. The mechanical contractor's responsibility, however, is limited to the HVAC system. The electrical contractor's responsibility is also limited. The mechanical and electrical permit applications are reviewed and inspected by different staff at the building department than those involved in the building shell.

To address this issue, the Standard assumes that all buildings will be heated in climate zones 3 through 8. The building official can make an exception to this rule for special cases, but the default assumption is that all shell buildings in zones 3 through 8 are conditioned. (See discussion of Space-Conditioning Categories in the Reference section.) In zones 1 and 2, it's okay to assume the building is unconditioned without getting the building official's approval. If the building official approves a space as semiheated or unconditioned, it must be clearly designated as such on the floor plans.

Alteration of Existing Buildings

The following types of building envelope alterations are exempt from compliance with the Standard, provided they do not increase the energy usage of the building (see § 5.1.3):

- Installing storm windows over existing glazing. This typically improves the performance of the building envelope by reducing both the U-factor and the solar heat gain coefficient (SHGC).
- Replacing broken or damaged glazing in an existing sash and frame, provided that the U-factor and SHGC of the replacement glass are equal to or lower than those of the original glass. In-kind replacement glazing will always satisfy this exception. However, see (g) below if glass and sash are being replaced in an existing frame, or if glass, sash, and frame are being replaced.
- Altering roofs, ceilings, walls or floors that have cavities, as long as the cavity is filled with insulation having an insulating value of at least R-3.0 per inch (R-0.02/mm). Filling the cavity with insulation is easy to achieve and cost-effective.
- Altering walls and floors that have no framing cavities. Insulating these types of construction presents practical difficulties and may not be cost-effective unless special circumstances exist.
- Replacing a roof membrane, as long as neither the roof sheathing nor the

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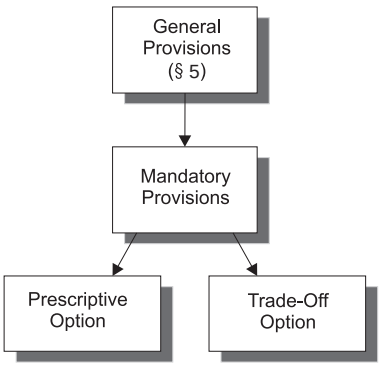

Figure 5-D—Envelope Compliance Options

existing insulation is exposed. However, if the roof is stripped down to the level of the sheathing or insulation, then the roof must be insulated to the Standard (unless there is insulation below the sheathing).

- Replacing exterior doors does not trigger the requirement for a vestibule or revolving door. However, if a vestibule or revolving door exists, it may not be removed.
- Replacing existing fenestration (windows, plastic panels, glass blocks, glass doors, or skylights), as long as the area of fenestration that is being replaced is less than 25% of the total fenestration area of the existing building. Also, the U-factor and SHGC of the replacement fenestration must be equal to or less than the original fenestration. If the replacement fenestration area exceeds 25%, then the replacement fenestration that is installed must meet the requirements of the Standard.

Compliance Methods (§ 5.2)

In addition to the general requirements, the Standard contains Mandatory Provisions that must be satisfied in all cases. These include requirements for installing insulation, limiting air leakage, and rating doors and windows. After satisfying the Mandatory Provisions, either the Prescriptive Building Envelope Option or the Building Envelope Trade-Off Option (see Figure 5-D) may be followed.

Prescriptive Building Envelope Option

The prescriptive building envelope option consists of 8 criteria sets that are appropriate for each of the climate zones (see Climate section below). Each criteria set is a single page that summarizes all the prescriptive requirements for that location, including insulation levels for opaque components such as roofs, walls, and floors. For above-grade opaque constructions, the design criteria are expressed in terms of a maximum U-factor or a minimum R-value. If insulation is installed that has the prescribed R-value, then there is no need to demonstrate compliance with the thermal performance (U-factor) of the construction assembly. When using the maximum U-factor criteria, Appendix A of the Standard has defaulted U-factors for most constructions so that you rarely have to calculate a U-factor to show compliance.

Prescriptive design criteria are also provided for fenestration (windows, glass doors, glass block, plastic panels, and skylights). The fenestration criteria depend on the frame type (in the case of windows) and the skylight-roof ratio (in the case of skylights). The Prescriptive Building Envelope Option limits the window-wall ratio to 40% of the gross exterior wall and limits the skylight-roof ratio to 5% of the roof area. The fenestration criteria are expressed in terms of maximum solar heat gain coefficient (SHGC) and maximum U-factor. Visible light transmission (VLT) is also considered when the Building Envelope Trade-Off Option is used.

Example 5-A—Refrigerated Warehouse, Denver, Colorado

Q

A refrigerated warehouse in a food processing facility in Denver, Colorado, must be maintained at a temperature of 45°F. Do the building envelope standards apply to this warehouse?

A

No. The purpose of the cooling system is to maintain the quality of the goods stored in the warehouse. The building is exempt from the Standard because it is used primarily for a commercial process. However, this does not mean that the envelope of the refrigerated warehouse should not be insulated—quite the contrary. Since the temperature difference between the inside and the outside of the building is much greater in the summer, more insulation than required by the Standard can easily be cost justified.

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With the prescriptive option, each envelope component must separately satisfy the requirements of the Standard, although it is possible to do some area-weighted averaging such that one construction could fail to meet the Standard as long as other constructions perform better. Area-weighted averaging is allowed if there are multiple assemblies within a single class of construction and a single space-conditioning category. R-values cannot be averaged, only U-factors, C-factors, F-factors, and SHGCs. Building Envelope Trade-Off Option

This method offers the designer more flexibility. The thermal performance of one envelope component such as the roof can fail to meet the prescriptive requirements as long as other components perform better than what is required. Trade-offs are permitted only between building envelope components. It is not possible, for instance, to make trade-offs against improvements in the lighting or HVAC systems.

Using the envelope trade-off option is more work than the prescriptive method. It's necessary to calculate the surface area of each exterior and semi-exterior surface.

Wall areas must also be calculated separately for each orientation. The methods used to make envelope trade-offs are documented in Appendix C of the Standard and incorporated in software called EnvStd (for envelope standard), which is provided on the CD distributed with this Manual. The EnvStd program runs on computers that use Windows™ NT/XP/Vista operating systems.

The major differences between the prescriptive and envelope trade-off options are shown in Table 5-A.

Energy Cost Budget Method

If neither the prescriptive nor the envelope trade-off methods are suitable, the energy cost budget method can be used (see § 11). With this option, trade-offs can be made between the building envelope and the lighting and/or mechanical systems. (In all cases, however, the design must comply with the Mandatory Provisions in § 5.4.)

The building performance rating method in Appendix G (similar to the ECB Method) is also useful when you want to know how much more energy efficient a building is than the minimum requirements of the Standard. Several labeling and recognition programs exist that require buildings to perform a certain percentage better than ANSI/ASHRAE/IESNA *Standard 90.1*. Two examples include the Environmental Protection Agency (EPA) EnergySTAR™ program and the U.S. Green Building Council's LEED™ (Leadership in Energy and Environmental Design) rating system.

Table 5-A—Comparison of Building Envelope Prescriptive and Trade-Off Options

	Prescriptive Option	*Building Envelope Trade-Off Option*
Fenestration area	Window area is limited to 40% of the gross exterior wall area and skylights are limited to 5% of the roof area.	Fenestration area greater than 40% is are permitted if the performance of envelope components is improved over that required by the prescriptive requirements.
Area take-offs	It is only necessary to verify that the window-wall ratio is less than 40% and/or the skylight-roof ratio if all components meet the prescriptive requirements.	Surface areas must be calculated for each type and class of construction. Window and wall area must be separately calculated for surfaces facing the major compass points (N, S, E, W) plus NE, SE, SW, and NW.
U-factor compliance	Not necessary if the R-value option is used.	Required, but users can choose from default values contained in EnvStd.

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Example 5-B—Warehouse, Oakland, California

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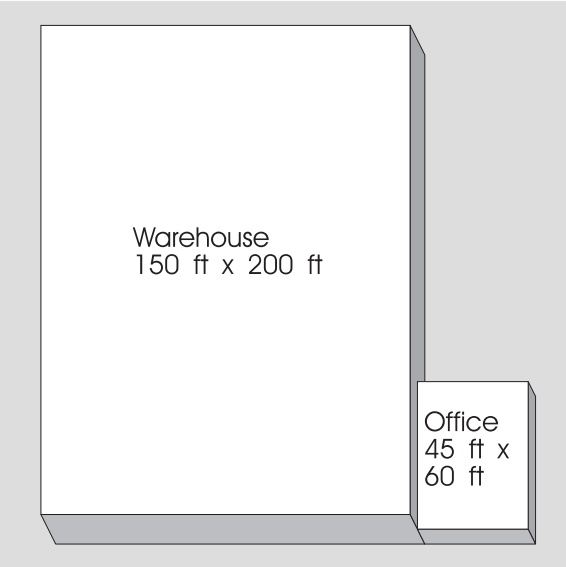
A 30,000 ft²-warehouse in Oakland, California, will be used to store household appliances until they are distributed to retail outlets. A 2,700 ft²-office is attached to the warehouse. The warehouse is designed with two 100,000-Btu/h output unit heaters and is not air-conditioned. A packaged single-zone heating and cooling system will serve the office area. How do the building envelope standards apply to this facility?



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The envelope standards clearly apply to the office portion of the building—the portion that is both heated and cooled. The heating system in the warehouse area has a capacity of 6.7 Btu/ft² (200,000 Btu/h divided by 30,000 ft²). Oakland is in climate zone 3 and for this climate, the heating system would have to be larger than 10 Btu/h·ft² in order to be considered conditioned space (see Conditioned Space in the Reference section). However, the space is considered semiheated since the heating system is greater than 3.4 Btu/h·ft². The walls and roofs that separate the office from the outdoors are exterior and the nonresidential criteria apply. The walls and roofs that separate the warehouse either from the exterior or from the office are semi-exterior and the criteria for semiheated spaces apply. Since Oakland is in climate zone 3, the building official must approve designation of the warehouse as semiheated space.

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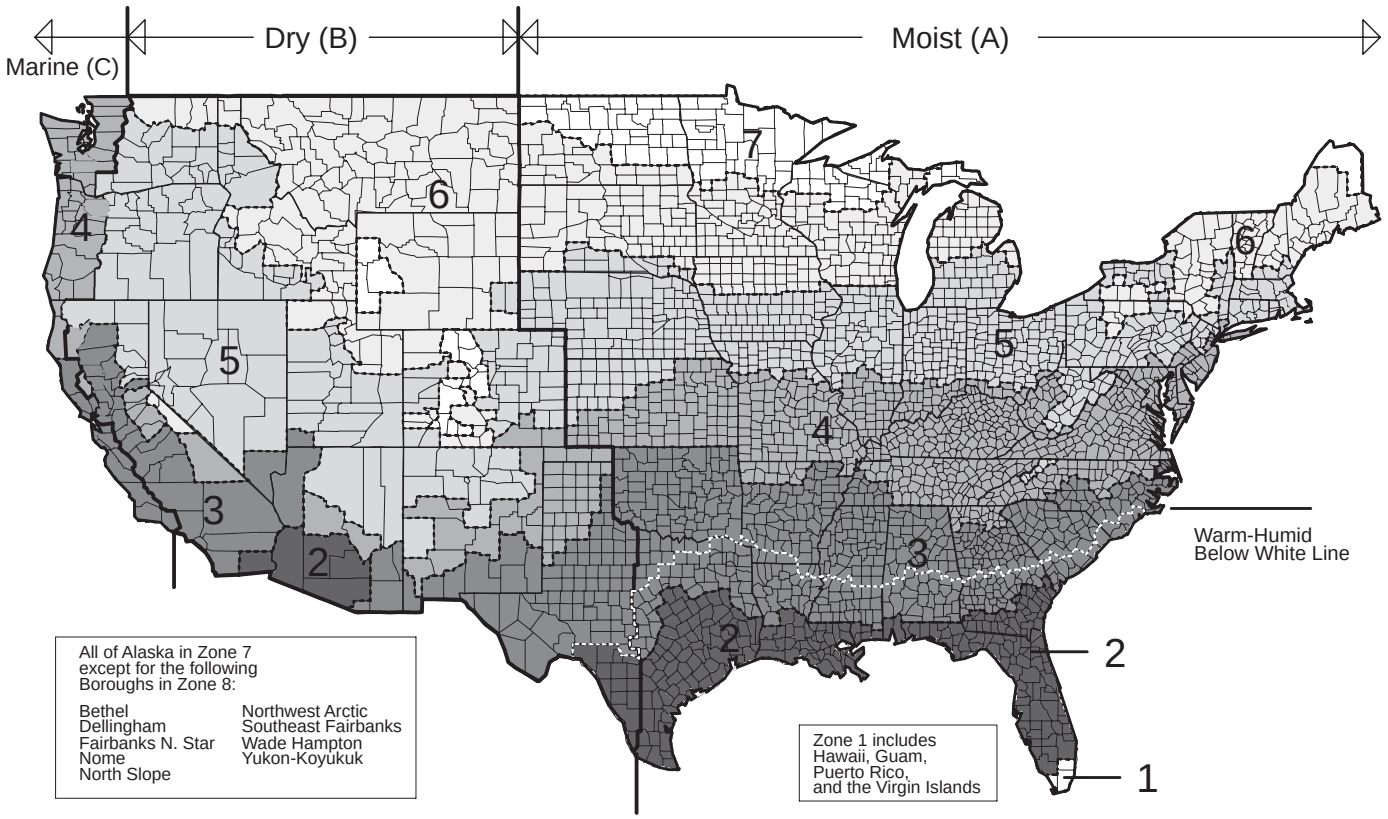

Figure 5-E—Climate Zones for United States Locations

Climate Zones (§ 5.1.4)

The Standard has eight envelope criteria sets, one for each of the eight thermal climate zones. Each building envelope criteria set is presented as a separate table. Figure 5-E shows the climate zone boundaries for the United States. Each county in the United States belongs to one and only one climate zone. Climate zones 1 through 8 generally move from south to north, also from lower to higher elevation, becoming gradually colder as the number gets higher. Climate zone 1 is the warmest and includes Hawaii and the southern tip of Florida. Alaska is not shown on the map but fits in both climate zone 7 or 8. Climate zone 8 is the coldest. It includes the north slope, Nome, and Fairbanks; Anchorage, Juneau, the Kenai peninsula and other southern parts of Alaska are in climate zone 7. Climate zone 7 is the coldest in the Continental US. It includes northern Maine, northern Minnesota, North Dakota, northern Michigan, and northern Wisconsin.

In addition to being defined by its thermal characteristics, locations are also defined by their wetness or humidity. This is identified by a letter: A, B, or C. Zone A includes the eastern part of the United States where summers are usually humid and air conditioners are typically required to remove water from outdoor air in order to maintain comfortable conditions. Zone B includes the generally dry western states where humidity control is generally not an issue in the summer. Zone C includes the cool Washington, Oregon and California coasts that are strongly influenced by cold Pacific Ocean waters. Specific information on relative humidity can be found in Appendix D, Table D-4.

The building envelope criteria only depend on the thermal zones, not the moisture zones.

The easiest way to determine the climate zone for a particular location is to look at Appendix B of the Standard. Table B-1 includes all of the counties in the United States and a climate zone is identified for each. Table B-2 lists climate locations in Canada and Table B-3 lists climate locations in many other countries.

For Canadian or international cities that are not listed in Appendix B, you can select a city that has similar climate conditions. Alternatively, if you have climate data for the city, you can use the procedures in § B2 of Appendix B to determine the climate zone.

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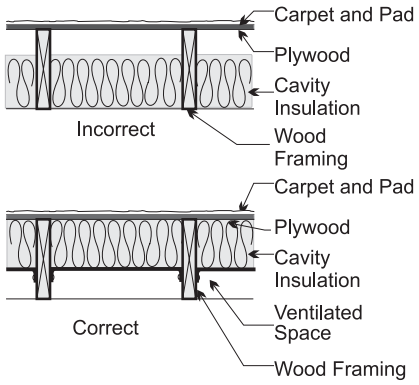

Figure 5-F—Insulation in Substantial Contact

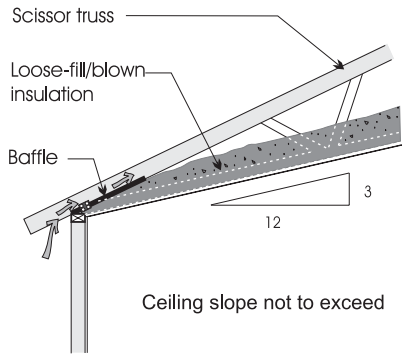

Figure 5-G—Blown Insulation Above Sloping Ceiling

For most United States cities, the climate zone map in Figure 5-E and the listing in Table B-1 of Appendix B will be enough to determine the appropriate climate zone. Some U. S. counties, however, have significant elevation changes within the county that affect climate. In these instances, if there are recorded historical climatic data available for a construction site, Table B-3 of Appendix B may be used to determine the climate zone. Such a determination requires the approval of the authority having jurisdiction.

Space-Conditioning Categories (§ 5.1.2)

The envelope requirements apply to three types of spaces: nonresidential, residential, and semiheated. Both nonresidential and residential are conditioned spaces; for these the Standard calls for more insulation and more control of heat gain through fenestration. Most spaces within buildings that are covered by the Standard will fall into one of these three categories.

The residential space category includes spaces in buildings used primarily for living and sleeping. Examples include, but are not limited to, dwelling units, hotel/motel guest rooms, dormitories, nursing homes, patient rooms in hospitals, lodging houses, fraternity/sorority houses, hostels, prisons, and fire stations.

The nonresidential space category includes all other conditioned spaces covered by the Standard including, but not limited to, offices, retail shops, shopping malls, theaters, restaurants, meeting rooms, etc. The defining characteristic of nonresidential spaces is that they are not continuously conditioned. Offices, for instance, are typically conditioned only during the day on weekdays and part of the day on Saturday; they are generally not conditioned on Sundays and holidays. Residential spaces, on the other hand, are conditioned on a more-or-less continuous basis. A greater investment in energy efficiency can be justified for spaces that are continuously conditioned, and this is the basis of the distinction between these two space categories.

As discussed earlier, under certain circumstances, spaces can be either semiheated or unconditioned. Examples of semiheated spaces are warehouses or light manufacturing facilities that have only a limited heating system (no cooling). In order to qualify as a semiheated space, the heating system must be sufficiently small, with the exact maximum output capacity depending on the climate (see Conditioned Space in the Reference section). Unconditioned spaces are spaces that have neither a heating nor a cooling system. The general assumption is that all spaces in climates 3 through 8 are conditioned. Declaring a space as semiheated or unconditioned is an exception that must be approved by the building official, although the Standard has very specific criteria for making the determination. The designer should label semiheated and unconditioned spaces on the construction plans that are submitted with the building permit application. This will enable the building official to verify that the spaces are truly semiheated or unconditioned.

Some spaces are considered conditioned even though they may not have a heating system or cooling system that directly serves the space. This type of space is called indirectly conditioned (see Conditioned Space in the Reference section). The nonresidential and residential building envelope requirements apply to indirectly conditioned space in the same way that they apply to directly conditioned space. Examples of indirectly conditioned spaces are storage rooms that are adjacent to conditioned spaces, toilets that exhaust air from conditioned spaces, or electrical closets that are adjacent to conditioned spaces.

Most of the time it will be easy to identify indirectly conditioned spaces. When there is uncertainty, the Standard has two criteria to determine what constitutes indirectly conditioned space:

1. The heat transfer rate to conditioned space is larger than the heat transfer rate to the exterior (ambient conditions). This will cause the

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temperature of the space to more closely track interior temperature.

2. There is an air transfer rate between the space and conditioned space that exceeds three air changes per hour (ACH).

See Conditioned Space in the Reference section for more information and examples of indirectly conditioned space.

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Mandatory Provisions (§ 5.4)

Compliance with the Standard requires that the Mandatory Provisions be satisfied in all cases. After that, the designer can choose to comply with the Prescriptive Building Envelope Option (§ 5.5), the Building Envelope Trade-Off Option (§ 5.6), or the Energy Cost Budget Method (§ 11).

Before reviewing this Mandatory Provisions section, you should read the General Information section at the beginning of this chapter so that you understand concepts such as conditioned, semiheated, and unconditioned spaces, as well as concepts such as exterior and semi-exterior envelope components. The General Information section also explains how to find the criteria set that applies to your building location. It is important to have a good grasp of these concepts before reviewing the envelope requirements.

Insulation (§ 5.8.1)

The first set of mandatory requirements addresses the proper installation and protection of insulation materials. Issues that are covered include compression of insulation, installing insulation on sloping ceilings and around recessed equipment, and protecting insulation from physical or moisture damage.

Installation (§ 5.8.1)

Section 5.8.1.2 requires that insulation materials be installed according to the manufacturer's recommendations and in a manner that will achieve the rated insulation R-value. For example, you can't take credit for R-19 insulation if you squeeze it into a 2x4 wall space (its normal 5.5 in. thickness would be compressed to 3.5 in.). Compressing the insulation reduces the effective R-value and the thermal performance of the construction assembly (see Table A9.4C in Appendix A of the Standard).

However, there is an exception to the insulation compression rule for metal buildings where insulation is typically draped over the metal purlins and compressed at the supports. The U-factors for metal buildings that are published in Appendix A account for this compression. Insulation can also be compressed if you perform U-factor calculations and account for the effect of compression; in other words, you can't use the precalculated U-factor tables published in Appendix A of the Standard if the insulation is compressed.

The Standard also limits the use of loose-fill or blown insulation to ceilings that have a slope not exceeding three in twelve. The obvious reason for this is to prevent the insulation from tumbling to one side, leaving the top portion of the ceiling uninsulated. In addition, baffles should be installed at the eaves if the attic is ventilated from that location. The purpose of the baffles is to prevent the loose insulation from blocking the vent area or being lost through the ventilation opening.

Substantial Contact (§ 5.8.1.5)

Section 5.8.1.5 requires that insulation be installed in a permanent manner and in substantial contact with the inside surface of the construction assembly. If the insulation does not entirely fill the cavity, the air gap should be on the outside surface. Maintaining substantial contact is particularly important (and problematic) for batt insulation installed between floor joists. Without proper support, gravity will cause the insulation to fall away from the floor surface, leaving an air gap above the insulation. Air currents will ultimately find their way to the gap, and when they do, the effectiveness of the insulation will be substantially reduced. The Standard calls for insulation supports in underfloor constructions to be spaced no further than 24 inches on center (o.c.).

There is an exception for construction assemblies that use reflective materials and rely on an air gap next to the interior surface. In hot climates, some insulation products use layers of reflective materials, each with a low emittance. This exception is meant to allow these types of insulation products to be used when appropriate.

Recessed Equipment (§ 5.8.1.6)

Section 5.8.1.6 requires that recessed equipment not reduce the thickness of the insulation. Examples of recessed equipment are lighting fixtures, wall heaters, HVAC ducts, diffusers, VAV boxes and other types of electrical or mechanical equipment. There are some exceptions to this requirement:

1. Equipment can be recessed if the area affected is less than one percent of the total roof/ceiling area. For instance, lighting fixtures may penetrate an insulated ceiling as long as the area of the openings in the insulation is less than one percent of the total ceiling area. It is acceptable for all the one percent to be located in one roof/ceiling area; there is no need for the recessed equipment to be uniformly distributed across all roof/ceiling surfaces. Miniaturized lighting equipment such as fiber optics would be significantly less than one percent.
2. A second exception applies to cases where the entire construction assembly is covered to the full depth required. This might be achieved if Type IC (Insulation Contact) lighting fixtures were used and additional insulation were placed over the top of the fixtures. Most building codes require that a minimum clearance of 3 in. be maintained between the lighting fixture and the insulation. This is a problem with all insulation systems since large holes or discontinuities result. Type IC lighting

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fixtures are rated by Underwriters Laboratory (UL) and permit insulation to be in direct contact. The additional cost of Type IC fixtures is offset by the savings from not having to construct dams around the fixtures to maintain the minimum clearance.

3. A third exception applies when the effect of the holes in the insulation or the reduced insulation thickness is taken into account in the calculations. In this case, the designer might divide the ceiling into areas that have penetrations and those that don't and then show that the area-weighted average U-factor is less than the Standard requires.

Even with these exceptions, however, the infiltration barrier must be maintained according to § 5.4.3.1. This will generally prohibit drop-in ceilings from being used as the exterior envelope element (see additional restrictions below).

Insulation above Suspended Ceilings (§ 5.8.1.8)
The Standard specifically prohibits installing insulation directly over suspended ceilings with removable ceiling panels. This is because the insulation's continuity is likely to be disturbed by maintenance workers. Also, suspended ceilings do not meet the Standard's infiltration requirements unless they are properly sealed. Compliance with this requirement could have a significant impact in some parts of the country, as it is common practice to install insulation over suspended ceilings. However, this practice must be avoided. If the insulation barrier is at the ceiling, many building codes will consider the space above the ceiling to be an attic and require that it be ventilated to the exterior. If vented to the exterior, air in the attic could be quite cold (or hot) and the impact of the leaky suspended ceiling would be made worse.

Insulation Protection (§ 5.8.1.7)
The Standard requires that insulation be protected from sunlight, moisture, landscaping equipment, wind, and other physical damage. Rigid insulation used at the slab perimeter of the building should be covered to prevent damage from gardening or landscaping equipment. Rigid insulation used on the exterior of walls and roofs should be protected by a permanent waterproof membrane or exterior finish. If mechanical or other equipment is installed in attics, access to this equipment must be provided in a way that won't cause compression or damage to the insulation. This may mean using walking boards, access panels, and other techniques to prevent damage to the insulation.

In situations such as vinyl-faced insulation installed inside warehouse roofs, where there is no ventilated airspace above the insulation and no solid surface such as gypsum board immediately below the insulation, the Standard requires that all seams be sealed with tape in order to provide an adequate vapor retarder. In this application, simply stapling the insulation is not adequate.

Apart from the situation described above where insulation is exposed, there are no mandatory requirements for moisture migration. However, the prudent designer should pay attention to moisture migration in all building construction. Vapor retarders prevent moisture from condensing within walls, roofs, or floors. Water condensation can damage the building structure and can seriously degrade the performance of building insulation and create many other problems such as mold and mildew. The designer should evaluate the thermal and moisture conditions that might contribute to condensation and make sure that vapor retarders are correctly installed to prevent condensation.

In addition to correctly installing a vapor retarder, it is important to provide adequate ventilation of spaces where moisture can build up. Most building codes require that attics and crawl spaces be ventilated, and some require a minimum one-inch clear airspace above the insulation for ventilation of vaulted ceilings. Even the wall cavity may need to be ventilated in extreme climates.

Fenestration and Doors (§ 5.8.2)

Fenestration and doors must be rated using procedures and methods specified in the Standard. Three fenestration performance characteristics are significant in the Standard: U-factor, solar heat gain coefficient (SHGC), and visible light transmittance (VLT). These are reviewed briefly below and explained in more detail in the Reference section of this chapter.

U-Factor (§ 5.8.2.4)
The U-factor of fenestration is very important to the energy efficiency of buildings, especially in cold climates. The U-factor must account for the entire fenestration construction, including the effects of the frame, the spacers in double glazed assemblies, and the glazing. There are a wide variety of materials, systems, and techniques used to manufacture fenestration products, and accurately accounting for these factors is of utmost importance when administering the Standard.

Fenestration U-factors must be determined in accordance with the National Fenestration Rating Council (NFRC) Standard 100. NFRC is a membership organization of window manufacturers, researchers, and others that develops, supports, and maintains fenestration rating and labeling procedures. Most fenestration manufacturers have their products rated

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and labeled through the NFRC program. Default U-factor values are provided in the Standard's Appendix A for fenestration products that do not have NFRC ratings. These default values assume the worst in terms of thermal performance.

While the NFRC certification program has included skylights since its inception, the basis for skylight ratings was shifted to a 20 degree slope in 2001. NFRC ratings are not commonly available for dome skylights, because of the plastic material and the varying air gap. Consequently, a more extensive default table is provided and intended for use during an interim basis only.

Table A8.1A of Appendix A has U-factors that can be used for skylights. This table offers credit for low-e coatings, frame types and other factors that affect thermal performance (see Reference section). When using the default table to take credit for low-e coatings, the emissivity of the low-e coating must be determined using NFRC Standard 301 and must be verified and certified by the glass manufacturer. NFRC ratings for specific products are always preferable to the generic values in Table A8.1A.

With Addendum 90.1ag (published with *Standard 90.1-2001*) glazed wall systems, including glass curtain walls used on large buildings, storefront glazing systems, and other similar products that are assembled at the construction site, as opposed to at the factory, must either be rated using NFRC procedures or the default U-factor, SHGC and VLT from Table A8.2. Since the performance values in Table A8.1A are based on uncoated clear glass in poorly performing metal frame, they do not offer any credit for low-e coatings, thermal break frames or any other advanced feature. In general, values from Table A8.1A will not achieve compliance with the fenestration requirements.

The NFRC procedure for site-built fenestration is described in NFRC 100. The NFRC ratings are based on computer simulations of various product options at standard sizes. (For curtain walls, the standard size specified is 2000 mm by 2000 mm, or approximately 79 in. by 79 in.) Multiple glass options can be included in one simulation matrix. The entire simulation matrix is then validated by a single physical test at the standard size. If the matrix for a product has previously been validated, then a new glass option can be added to the matrix by simulation alone. Simulations and tests must be done by an NFRC-accredited simulation and test laboratories.

Product certification consists of an 8 ½ by 11 in. NFRC Label certificate that lists the U-factor, SHGC, visible transmittance, the project address, how many of these fenestration products will be installed in the building project, the frame material supplier, the glazing material supplier, the glazing contractor, and the certification authorization. For additional information, visit the NFRC website at www.nfrc.org, or call 301-589-1776.

For garage doors that do not have NFRC ratings, U-factors may be determined in accordance with the Door and Access Systems Manufacturers Association (DASMA) Standard 105.

Solar Heat Gain Coefficient (§ 5.8.2.5)
Solar heat gain coefficient (SHGC) is a figure of merit on the solar gains that enter a building through fenestration products. In hot climates, SHGC is the most important performance characteristic of fenestration, more important than U-factor. See the Reference section for more information on the technical meaning of SHGC and for information on how to determine appropriate values.

The Standard requires that SHGC be determined in accordance with NFRC *Standard 200* and by a laboratory that has accreditation by NFRC or a similar organization. The fenestration product must also be labeled and certified by the manufacturer.

SHGC has replaced shading coefficient (SC) as the figure of merit for solar heat gain through fenestration products. SC may still be found, however, in older manufacturers' catalogs. SC does not account for the fenestration frame and is determined for the center-of-glass. Furthermore, SC is relative to ⅛ in. (3 mm) clear glass, whereas SHGC is relative to a perfectly transmissive glazing material. When SC is available, but not SHGC, the Standard allows SHGC to be established as 0.86 times the SC, provided that the SC is determined using a spectral data file in accordance with NFRC 300.

For skylights, the Standard provides default SHGC values in Table A8.1B. For other unlabeled fenestration products, see Table A8.2. However, the values in Table A8.2 do not account for low-e coatings reflective coatings and other technologies commonly used to reduce solar heat gains. In most instances, designers should obtain either SHGC or SC data from the manufacturer and use these data in compliance calculations.

Visible Light Transmittance (§ 5.8.2.6)
Visible light transmittance (VLT) is the third important performance characteristic of fenestration products. VLT is the ratio of light passing through the glazing to light passing through perfectly transmissive glazing. VLT is concerned only with the visible portion of the solar spectrum, as opposed to SHGC, which is the ratio of all solar radiation. VLT is important for buildings that incorporate daylighting. The prescriptive requirements do not place limits on VLT, but VLT is a

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factor when the Building Envelope Trade-Off Option is used.

The Standard requires that VLT be determined in accordance with NFRC *Standard 200* and that the VLT be verified and certified by the glazing manufacturer. While VLT may be listed in some glass manufacturers' catalogs, the VLT used in the trade-off approach in § 5.6 is an overall fenestration product value and includes glass, sash, and frame.

Air Leakage (§ 5.4.3)

The Standard requires that the building envelope be carefully designed to limit the uncontrolled entry of outdoor air into the building. Controlling infiltration is important to achieving energy-efficient buildings. Air leakage introduces sensible heat into conditioned and semiheated spaces. In climates with moist outdoor conditions, it is also a major source of latent heat. Latent heat must be removed by the air-conditioning system at considerable expense. The Standard has requirements for the sealing of building envelope elements, infiltration through doors and windows, air seals at loading dock doors, and vestibules to limit infiltration at main entrance doors to buildings. As with all of the mandatory requirements, the air leakage requirements must be met with all compliance approaches, even the energy cost budget method.

Building Envelope Sealing (§ 5.4.3.1)

The first set of air leakage requirements deals with inadvertent leaks at joints in the building envelope. In particular, the Standard states that exterior joints, cracks, and holes in the building envelope shall be caulked, gasketed, weather stripped, or otherwise sealed. The construction drawings and specifications should require the sealing, but special attention is needed in the construction administration phase

Example 5-C—Determining Fenestration Performance Characteristics for Curtain Wall in High-Rise Office

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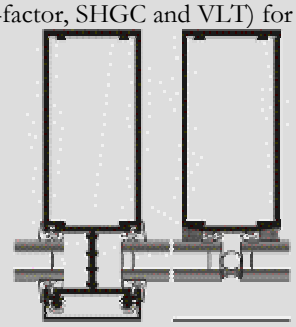
The designers of a glass curtain wall for a Boston office high-rise are proposing to use a double standard low-e glazing material and a standard thermally improved curtain wall framing system. The glazing manufacturers' literature shows a center-of-glass U-factor of 0.29, a SHGC of 0.23 and a VLT of 0.32. What are the options for determining the performance characteristics (U-factor, SHGC and VLT) for this fenestration system?



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There are two choices for determining the U-factor: either obtain NFRC data or use the defaults from Table A8.2. The U-factor default is 0.90. Table A8.2 also gives the SHGC default as 0.50 and the VLT default as 0.40. While these defaults could be used, they do not even come close to achieving compliance with the Standard.

The WWR for the proposed high-rise is 38% so from Table 5.5-5, the U-factor criteria is 0.45 and the SHGC criteria is 0.40.

Exception (b) to § 5.8.2.5, however allows the manufacturer's SHGC to be used in the calculations. Also, § 5.8.2.6 permits the manufacturer's VLT to be used for compliance if the envelope trade-off procedure is used. So the real problem in terms of compliance is the U-factor.

The NFRC option is more expensive and takes more time, but produces performance data that is fair and reasonable. The procedure for doing this is NFRC 100. The glazing contractor for curtain wall systems generally takes responsibility or obtaining ratings and certification using the NFRC procedure. The steps are as follows:

1. Identify the number of product lines that are contained in the building project.
2. For product lines that have not previously been simulated, arrange for an NFRC-accredited simulation laboratory to evaluate each product line.
3. For product lines that have not previously been tested, make an arrangement with an NFRC-accredited testing laboratory to test each product line.
4. Arrange for the glazing manufacturer and the extrusion manufacturer to provide standard-size samples for testing and to send them to the testing laboratory.
5. The NFRC-accredited independent agent (IA) then issues a label certificate that is kept on file in the general contractor's on-site construction office. The label certificate provides the same function as the temporary label that is required with manufactured fenestration products.

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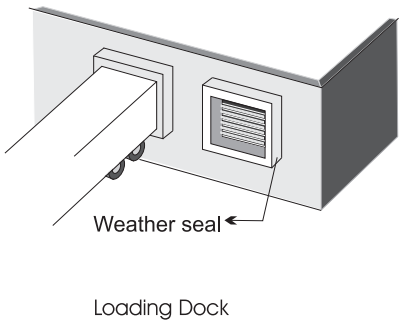

Figure 5-H—Loading Dock Weatherseal

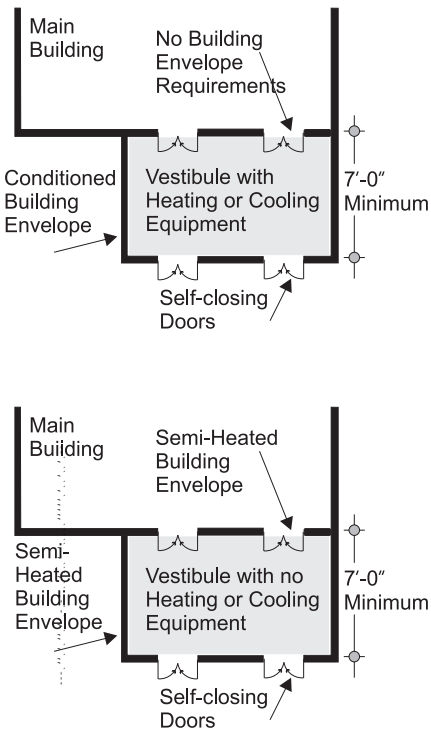

Figure 5-I—Vestibule Requirements

to assure proper workmanship. A tightly constructed building envelope is largely achieved through careful construction practices and attention to detail. Poorly sealed buildings can cause problems for maintaining comfort conditions when additional infiltration loads exceed the HVAC design assumptions. This can be a significant problem in high-rise buildings due to stack effect and exposure to stronger winds.

The Standard identifies several areas in the building envelope where attention should be paid to infiltration control. These include:

a. Joints around fenestration and door frames.

b. Junctions between walls and foundations, between walls at building corners, between walls and structural floors or roofs, and between walls and roof or wall panels.

c. Openings at penetrations of utility services through roofs, walls, and floors.

d. Site-built fenestration and doors.

e. Building assemblies used as ducts or plenums.

f. Joints, seams, and penetrations of vapor retarders.

g. All other openings in the building envelope.

The Standard also has requirements for limiting infiltration through mechanical air intakes and exhausts. These requirements are addressed in the mechanical section (§ 6) of the Standard, not in the building envelope section.

Fenestration and Doors (§ 5.4.3.2)
Fenestration products, including doors, can significantly contribute to infiltration. The Standard requires that most fenestration products have infiltration less than 0.4 cfm/ft² (2.0 l/s·m²). For glazed entrance doors that open with a swinging mechanism and for revolving doors, the Standard limits infiltration to 1.0 cfm/ft² (5.0 l/s·m²).

As with U-factors and solar optic properties (SHGC and VLT), the National Fenestration Rating Council (NFRC) has methods for ascertaining infiltration through fenestration. The Standard requires that NFRC *Standard 400* be used to determine infiltration through fenestration products. A laboratory accredited by the NFRC or other nationally recognized accreditation organizations must perform the ratings. The manufacturer must label each fenestration product with the appropriate infiltration data and certify that infiltration was correctly determined using NFRC *Standard 400*.

There are exceptions for some fenestration products. Field-fabricated fenestration and doors, including glazed wall systems, curtain walls, and storefronts, do not need to meet the infiltration requirements. Also, garage doors can use the Door and Access Systems Manufacturers Association's (DASMA) *Standard 105* to determine the infiltration rate.

Loading Dock Weatherseals (§ 5.4.3.3)
In climate zones 4 through 8, cargo doors and loading dock doors shall be equipped with weatherseals to restrict infiltration when vehicles are parked in the doorway. Manufacturers of loading dock doors offer these devices as an option. They usually consist of a vinyl-wrapped compressible foam block that is mounted around the perimeter of the door. The device forms a seal between the truck and the dock when the truck is parked at the dock (see Figure 5-H).

Vestibules (§ 5.4.3.4)
Vestibules or revolving doors are required for most building entrances. Building entrances are defined in Section 3.2 as the means ordinarily used to gain access to the building, so this does not include exits

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from fire stairwells or the handicapped access doors that might be adjacent to a revolving door. All the doors entering and leaving required vestibules must be equipped with self-closing devices and the distance between the doors must be at least 7 feet. If the vestibule contains any heating or cooling equipment, then the building envelope requirements for conditioned space shall apply to exterior surfaces separating the vestibule from the outside, and there are no requirements for the interior surface of the vestibule. If the vestibule does not contain any heating or cooling equipment, then the building envelope requirements for semi-heated space shall apply to the exterior and interior surfaces separating the vestibule from the outside and inside, respectively (see Figure 5-I).

There are a number of exceptions to the vestibule requirement:

- Revolving doors in building entrances are exempt.
- Climate zones 1 and 2 are exempt because the energy savings in these mild climates do not justify the expense.
- For climate zones 3 and 4, vestibules are not required in buildings less than four stories above grade and less than 10,000 ft² in area because, with less height and less extreme temperatures, the stack effect is smaller. The stack effect (along with wind effects) is one of the main drivers of infiltration. In addition, low-rise buildings are generally smaller and there is less traffic through the door. However, large low-rise buildings (such as big-box retail stores and supermarkets) have more foot traffic and so are not exempt.
- For climate zones 5 through 8 vestibules are not required when the building is smaller than 1,000 ft².
- Doors other than building entrances are exempt, such as those leading to service areas, mechanical rooms, electrical equipment rooms, or exits from fire stairways. There is less traffic through these doors and the vestibule may limit access for large equipment.
- Doors opening directly from dwelling units are exempt in all climate zones and for any number of stories or amount of building area. Therefore, for example, sliding and swinging doors in high-rise residential buildings opening out to decks or balconies are exempt.
- Doors which are not building entrances and that open from a space with an area less than 3,000 ft² (300 m²) are exempt. This is intended to apply to small retail tenants on the ground floor of a multi-story building that have an entrance directly from the outside into their small retail space.

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Prescriptive Option (§ 5.5)

This section describes the Prescriptive Building Envelope Option. This is the easiest way to comply with the building envelope criteria in the Standard. All of the design criteria (also called "criteria set," see Table 5-C) for a particular location are contained on a single page, including the criteria for nonresidential, residential, and semiheated space categories. Review the General Information section and the Reference section to ensure that you understand these terms as well as important concepts such as conditioned and unconditioned spaces and exterior and semi-exterior envelope components.

To determine the criteria set for your location, look up your city or county in Appendix B or use the procedures described in General Information (§ 5.1). When the Standard is adopted as a code, this process is further simplified because the adopting jurisdiction usually identifies the criteria set(s) that are to be used. For example, a State may choose to specify that a particular criteria table be used throughout a county or for multiple counties to simplify implementation.

While the Prescriptive Building Envelope Option is simpler to apply, you cannot make trade-offs when using this option. Each envelope component must comply with the requirements for that component. If you need more design flexibility, you can instead use the Building Envelope Trade-Off Option (§ 5.6) or the energy cost budget method (§ 11). Both of these permit trade-offs between envelope components and, in the case of the energy cost budget method, trade-offs between building systems. Neither the prescriptive tables nor the building envelope trade-off or the energy cost budget method can be used to bypass any of the mandatory requirements.

Opaque Areas (§ 5.5.3)

Opaque areas of the building envelope include roofs, walls, floors, below-grade walls, slabs, and opaque doors. Within each surface type, the Standard identifies classes of construction and gives separate design criteria for each class. Table 5-C shows example prescriptive criteria for St. Louis, Missouri, U.S. This table shows the criteria in inch-pound (I-P) units. The Standard also provides tables in metric (SI) units. The I-P and SI criteria are identical, except for the units used to express the requirements.

From these example criteria, you can see three columns for the nonresidential, residential, and semiheated space categories. Notice that the requirements for residential space categories are a little more stringent than the nonresidential requirements. The reason is that continuous heating and cooling of residential space categories is assumed, while nonresidential spaces are assumed to be conditioned only during the day and only partly on weekends. The nonresidential and residential criteria apply to exterior surfaces. Semi-exterior surfaces use the criteria for the semiheated space category.

Most of the time, the appropriate class of construction will be obvious. When there is doubt, refer to the Reference section for clarification. Table 5-B summarizes the defining characteristics of the various classes of opaque constructions and gives a thumbnail sketch of each.

There are two ways to meet the prescriptive requirements for opaque construction. The easiest way is to install insulation with an R-value that exceeds the criteria shown in the column labeled "Insulation Min. R-value." R-value criteria are given for all constructions except opaque doors. The R-value criteria apply only to the insulation materials and do not include sheathing, air gaps, interior finishes, or air films. When a single R-value is given, the Standard usually assumes that the insulation is located within a cavity in the construction. For instance, for metal- or wood-framed walls, a requirement of R-13 means that the insulation installed between the framing members has a thermal resistance at least as great as R-13.

Sometimes the R-value criteria have "ci" next to them. This stands for continuous insulation. This "ci" notation means that the insulation must be installed in a manner that is continuous and is uninterrupted by framing members or other construction elements that would reduce the thermal resistance of the insulation when installed in the construction. Notice that for the "Insulation Entirely above Deck" class of roof construction, all the R-value criteria have the notation "ci," as do most of the mass walls, mass floors and below-grade walls.

In addition to the R-value, there are also criteria for the overall thermal performance of the construction assembly. These are an alternative to using the R-value criteria. For roofs, walls, and floors, the overall thermal performance is expressed as a maximum U-factor. The U-factor takes into account all elements or layers in the construction assembly, including the sheathing, interior finishes, and air gaps, as well as exterior and interior air films. Appendix A of the Standard has tables of default U-factors for all classes of construction. For opaque doors, the U-factor is the only compliance option.

For below-grade walls, the overall thermal performance criteria are expressed as a C-factor. The C-factor includes all layers in the construction assembly but

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excludes the exterior air film and the soil's effect on the outside of the wall. For slabs, the overall thermal performance criteria are expressed as an F-factor. The F-factor is the heat loss through a lineal foot (meter) of slab perimeter.

When a building has more than one class of construction that falls within the same space-conditioning categories, area-weighted averaging can be performed using the U-factor, C-factor, or F-factor compliance option. Area-weighted averaging is not allowed for R-value compliance. Area-weighted averaging enables one construction assembly within the class to fail to meet the criteria as long as other constructions within the class exceed the requirement. However, the area-weighted average of all constructions within the class must be less than the U-factor, C-factor, or F-factor criteria. When doing area-weighted averaging, up to one percent of openings due to recessed equipment can be ignored. If the openings are greater than one percent, they need to be accounted for in the area-weighted average.

Roof Insulation (§ 5.5.3.1)

This section describes each of the classes of roof construction and how compliance may be achieved using the Prescriptive Building Envelope Option.

Insulation Entirely Above Deck

When using the R-value criteria for this class of construction, the insulation must be installed in a continuous manner and must have only limited interruptions (the R-value criteria have the "ci" notation). Some interruptions are inevitable and permitted as long as they do not exceed one percent of the surface area of the total roof area. Interruptions are typically required to provide structural supports for mechanical or other roof-mounted equipment.

When using the U-factor criteria, the thermal performance of the entire construction assembly, including any thermal bridges, is taken into account. With this option, the U-factor of the proposed assembly must be less than or equal to the criteria. When buildings have more than one construction belonging to this class, an area-weighted average can be calculated for the constructions and it is only necessary that the weighted-average U-factor be less than or equal to the criteria. For demonstrating U-factor compliance, use the U-factors from Table A2.2, or if allowed by § A1.2, U-factors can be determined using the methods and procedures described in Appendix A. This class of construction is simple and without thermal bridges. The series calculation method can be used (see Reference section).

Metal Building Roofs

When using the R-value criteria for metal building roofs, some details and notations need to be taken into account. When a single R-value is given, for instance "R-19," the requirement can be satisfied by either draping batt insulation over the structural supports or attaching mineral fiber insulation to the underside of the metal deck. In the first case, the batt insulation is compressed at the supports. In both cases, a thermal block with a thickness of at least 1 in. (25 mm) must be installed at the supports.

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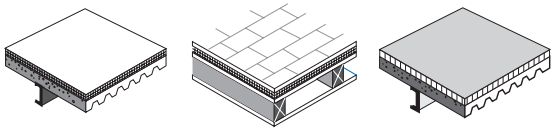
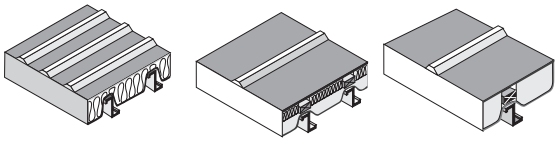
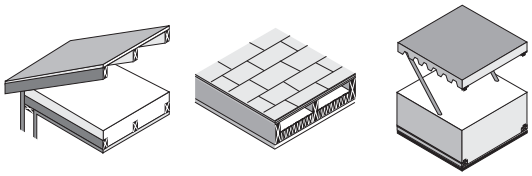
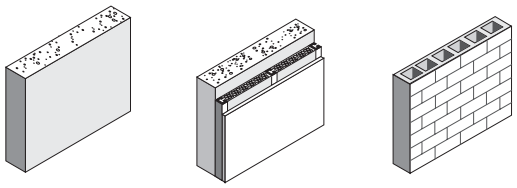
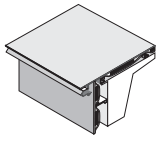
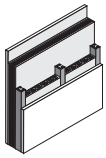
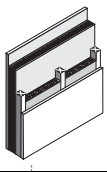
Table 5-B—Summary of Opaque Construction Classes

[continued on next page]

Sketch	*Class of Construction*	*Description*
Roofs		
	Insulation Entirely above Deck	The insulation is installed above a concrete, wood or metal deck in a continuous manner.
	Metal Building	Pre-fabricated metal roofs. The construction typically has a metal panel attached directly to metal purlins or joists. The insulation is typically draped over the purlins or joists and compressed at the supports.
	Attic and Other	Includes all roof constructions that do not qualify for one of the other classes of construction.
Walls, Above-Grade		
	Mass	Any concrete or masonry wall with a heat capacity exceeding 7 Btu/ft² ·°F (143 kJ/m² ·K). If the mass elements are constructed with lightweight materials with a unit weight not greater than 120 lbs/ft³ (1,920 kg/m³) then the HC must be greater than 5 Btu/ft² ·°F (102 J/m² ·K) in order to qualify as a mass wall.
	Metal Building	Pre-fabricated metal building walls. The construction typically has an exterior metal panel attached directly to horizontal metal purlins that span between the vertical building supports. The insulation is typically draped over the purlins and compressed at the supports.
	Steel-Framed	Walls with metal framing members. This is a very common construction type in nonresidential and some residential buildings, since noncombustible construction is required for many classes of construction.
	Wood-Framed and Other	Walls with wood framing or any type of wall construction that does not qualify as mass, metal building or steel-framed.

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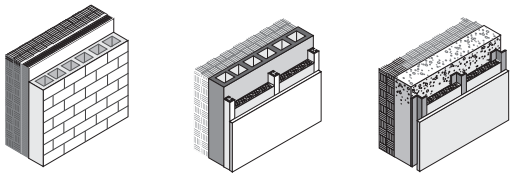
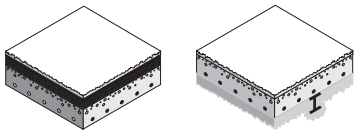
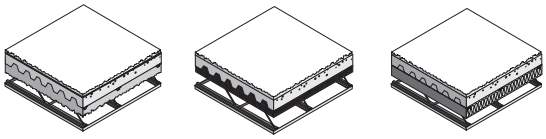
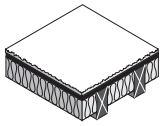
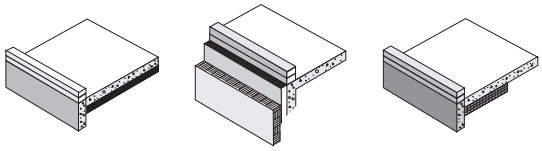
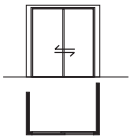
Sketch	*Class of Construction*	*Description*
Wall, Below-Grade		
	Below-Grade Wall	Any type of wall that is below grade. The outer surface of the wall is in contact with the earth, and the inside surface is adjacent to conditioned or semiheated space.
Floors		
	Mass	Any floor with a heat capacity exceeding 7 Btu/ft² ·°F (143 kJ/m² ·K). If the mass elements are constructed with lightweight materials with a unit weight not greater than 120 lbs/ft³ (1,920 kg/m³), then the HC must be greater than 5 Btu/ft² ·°F (102 J/m² ·K) in order to qualify as a mass floor.
	Steel-Joist	Any floor that is constructed with metal joists or purlins in such a manner that the metal-framing members interrupt the insulation continuity.
	Wood-Framed and Other	Floors that are framed with wood members and any other type of floor construction that is not of mass or steel-joist construction.
Slab-On-Grade Floors		
	Unheated	No heating elements either within or below the slab.
	Heated	Heating elements located within or below the slab.
Opaque Doors		
	Swinging	Opaque doors with hinges on one side and revolving doors (glazed doors are included with vertical fenestration).
	Non-Swinging	Rollup, sliding and other doors that are not swinging.

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Table 5-C—Example Prescriptive Criteria Set, St. Louis, Missouri

(This is Table 5.5-4 in the Standard.)

Building Envelope Requirements for Climate Zone 4 (A,B,C)									
	NONRESIDENTIAL			RESIDENTIAL			SEMIHEATED		
OPAQUE ELEMENTS	Assembly Maximum	Insulation Min. R-Value		Assembly Maximum	Insulation Min. R-value		Assembly Maximum	Insulation Min. R-Value	
Roofs									
Insulation Entirely above Deck	U-0.048	R-20.0 ci		U-0.048	R-20.0 ci		U-0.173	R-5.0 ci	
Metal Building	U-0.065	R-19.0		U-0.065	R-19.0		U-0.097	R-10.0	
Attic and Other	U-0.027	R-38.0		U-0.027	R-38.0		U-0.053	R-19.0	
Walls, Above-Grade									
Mass	U-0.104	R-9.5 ci		U-0.090	R-11.4 ci		U-0.580	NR	
Metal Building	U-0.113	R-13.0		U-0.113	R-13.0		U-0.134	R-10.0	
Steel-Framed	U-0.064	R-13.0 + R-7.5 ci		U-0.064	R-13.0 + R-7.5 ci		U-0.124	R-13.0	
Wood-Framed and Other	U-0.089	R-13.0		U-0.064	R-13.0 + R-3.8 ci		U-0.089	R-13.0	
Wall, Below-Grade									
Below-Grade Wall	C-1.140	NR		C-0.119	R-7.5 ci		C-1.140	NR	
Floors									
Mass	U-0.087	R-8.3 ci		U-0.074	R-10.4 ci		U-0.137	R-4.2 ci	
Steel-Joist	U-0.038	R-30.0		U-0.038	R-30.0		U-0.069	R-13.0	
Wood-Framed and Other	U-0.033	R-30.0		U-0.033	R-30.0		U-0.066	R-13.0	
Slab-On-Grade Floors									
Unheated	F-0.730	NR		F-0.540	R-10 for 24 in.		F-0.730	NR	
Heated	F-0.860	R-15 for 24 in.		F-0.860	R-15 for 24 in.		F-1.020	R-7.5 for 12 in.	
Opaque Doors									
Swinging	U-0.700			U-0.700			U-0.700		
	U-0.500			U-0.500			U-1.450		
FENESTRATION	Assembly Max. U	Assembly Max. SHGC		Assembly Max. U	Assembly Max. SHGC		Assembly Max. U	Assembly Max. SHGC	
Vertical Glazing, 0-40% of Wall									
Nonmetal framing, all[a]	U-0.40	SGHC-0.40 all		U-0.40	SGHC-0.40 all		U-1.20	SGHC-NR all	
Metal framing, curtainwall/storefront[b]	U-0.50			U-0.50			U-1.20		
Metal framing, entrance door[b]	U-0.85			U-0.85			U-1.20		
Metal framing, all other[b]	U-0.55			U-0.55			U-1.20		
Skylight with Curb, Glass, % of Roof									
0-2.0%	U_{all}-1.17	$SHGC_{all}$-	0.49	U_{all}-0.98	$SHGC_{all}$-	0.36	U_{all}-1.98	$SHGC_{all}$-	NR
2.1-5.0%	U_{all}-1.17	$SHGC_{all}$-	0.39	U_{all}-0.98	$SHGC_{all}$-	0.19	U_{all}-1.98	$SHGC_{all}$-	NR
Skylight with Curb, Plastic, % of Roof									
0-2.0%	U_{all}-1.30	$SHGC_{all}$-	0.65	U_{all}-1.30	$SHGC_{all}$-	0.62	U_{all}-1.90	$SHGC_{all}$-	NR
2.1-5.0%	U_{all}-1.30	$SHGC_{all}$-	0.34	U_{all}-1.30	$SHGC_{all}$-	0.27	U_{all}-1.90	$SHGC_{all}$-	NR
Skylight without Curb, All, % of Roof									
0-2.0%	U_{all}-0.69	$SHGC_{all}$-	0.49	U_{all}-0.58	$SHGC_{all}$-	0.36	U_{all}-1.36	$SHGC_{all}$-	NR
2.1-5.0%	U_{all}-0.69	$SHGC_{all}$-	0.39	U_{all}-0.58	$SHGC_{all}$-	0.19	U_{all}-1.36	$SHGC_{all}$-	NR

a Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.

b Metal framing includes metal framing with or without thermal break. The all other subcategory includes operable windows, fixed windows, and non-entrance.

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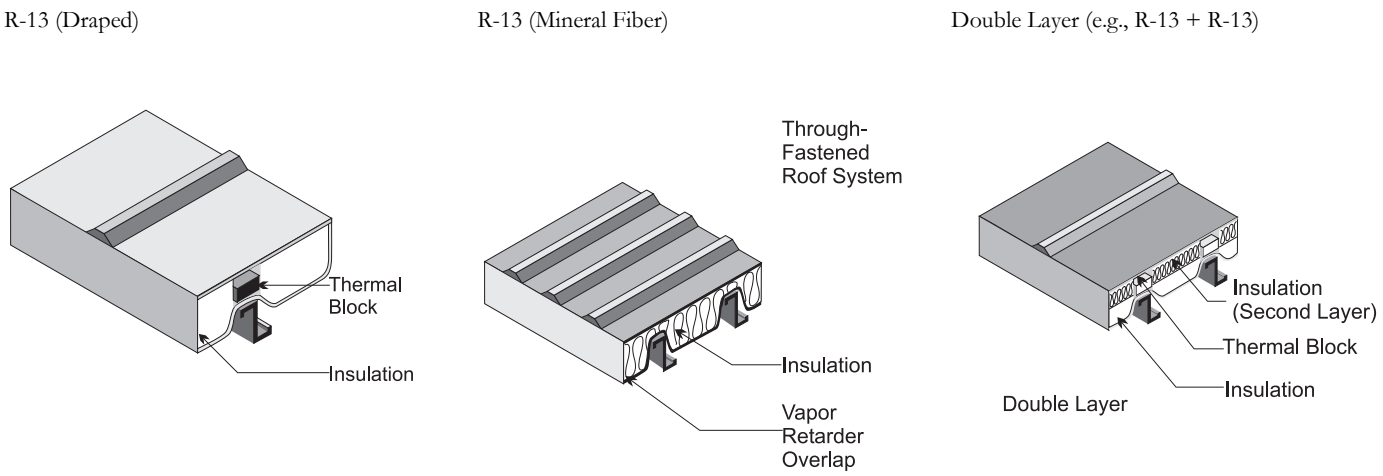

Figure 5-J—Prescriptive Building Envelope Option, Metal Building Roofs

Sometimes, two R-values are given as criteria, for instance "R-13 + R-13ci." This indicates double layers of insulation. The first layer is installed using one of the techniques described in Table 5-C, but the second R-value with the "ci" subscript is required to be continuous. Figure 5-J shows the methods of complying with the R-value criteria for metal building roofs. Spacer blocks may be used with standing seam roof types, but not with through fastened systems. When using the U-factor criteria for metal building roofs, take values from Table A2.3 of Appendix A of the Standard or, if allowed by § A1.2, use calculation procedures specified in Appendix A.

Attics and Other Roofs

This class of construction includes all roof constructions that are a not metal building roof or that do not have the insulation installed entirely above the deck. Examples of roof constructions in this class include:

- Attics with either wood or metal trusses;
- Roofs above plenum spaces where the insulation is installed on the underside of the deck;
- Single rafter roofs; and
- Any other type of roof that is not a metal building roof and does not have insulation entirely above the deck.

Attics are a common roof construction in this class. Attics are usually ventilated to the exterior and the insulation is installed above the ceiling. The Standard permits the insulation depth to be reduced near the eaves, since this was accounted for in developing the R-value requirements and in developing the default U-factor tables in Appendix A. When the depth of the insulation required by the Prescriptive Building Envelope Option is greater than the depth of the bottom chord of the truss, the insulation must extend over the top of the bottom chord of the truss.

Single rafter roofs are another common roof construction that belong to this class. For this construction, framing members (usually wood framing members) have exterior sheathing attached to one side and the interior finish attached to the other side. The depth of the framing member limits the depth of the cavity. When insulation required by the Standard has a thickness too large to fit in the cavity, it is only necessary to install insulation at a depth that will fill the cavity and still leave an inch or so for ventilation. Table 5-E shows the minimum R-value of insulation that must be installed for 2x6, 2x8 and 2x10 nominal size framing members. For single-rafter roofs, the minimum insulation that must be installed is the lesser of the values in Table 5-E or the requirement in the criteria set.

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For demonstrating U-factor compliance, use the U-factors from Table A2.4 for attics and single-rafter roofs, and use Table A2.5 for attic roofs with steel joists. If allowed by § A1.2, Appendix A specifies calculation procedures that can be used. These are explained in the Reference section of this chapter, since they apply to both the prescriptive and envelope trade-off options.

Cool Roofs

A cool roof is a term that applies to roof surfaces that have both a high reflectance and a high emittance. In hot climates, cool roofs are an effective way to reduce solar gains through the roof. The properties of a cool roof can be achieved by applying a coating to the roof's outside surface or using a material (usually a single-ply membrane) that has both a high reflectance (light color) and a high emittance. The light color reflects sunlight and heat away from the building, and the high emittance allows heat to escape when the surface becomes heated. Some surfaces, such as galvanized metal, have a high reflectance but low emittance. These surfaces reflect heat, but heat that is absorbed cannot easily escape. Other surfaces, such as dark paint, have a high emittance but a low reflectance. These surfaces allow heat to escape, but do a poor job of reflecting heat that strikes the surface.

Table 5-D—Emittance and Reflectance Values to Achieve an SRI of 82

Emittance	Reflectance
0.10	0.810
0.15	0.800
0.20	0.790
0.25	0.785
0.30	0.775
0.35	0.765
0.40	0.760
0.45	0.750
0.50	0.740
0.55	0.730
0.60	0.725
0.65	0.715
0.70	0.705
0.75	0.700

In climate zones 1, 2 and 3, the Standard recognizes the cooling benefits of a cool roof surface and provides alternative thermal performance criteria when a qualifying cool roof is installed. The alternative U-factors are specified in Table 5.5.3.1. In order to qualify for the alternative criteria, the roof shall have the following characteristics:

1. the surface must have an initial solar reflectance equal to or greater than 0.70;
2. the surface must have an initial thermal emittance equal to or greater than 0.75 , and .
3. the roof cannot be over a ventilated attic, above a semiheated space, or over a heated only space. Note that while Table 5.5.3.1 gives criteria for "Attic and other" roofs, these criteria may not be used with attics if the attic is ventilated.

Qualifying roof products shall be tested and labeled by the Cool Roof Rating Council using procedure CRRC-1. Note that for some cool roof products, the CRRC publishes 3-year aged values for reflectance and emittance. These aged values should be considered when selecting cool roof products, but are not relevant in determining compliance with the Standard.

As an alternative to separately meeting the reflectance and emittance criteria,, a cool roof can qualify if it has a Solar

Example 5-D—Cool Roof in Georgia

Q

The building plans for a proposed building in Savanna, Georgia call for a reflective roof coating with a thermal emittance of 0.40 and an initial solar reflectance of 0.78. The roof has insulation entirely over the deck and has a U-factor of 0.067. Does this building meet the prescriptive Roof U-factor criterion?

A

The roof U-factor does not meet the requirement in Table 5.5-3 which calls for a roof U-factor of 0.063 or lower. The proposed design U-factor does meet the requirements of Table 5.5.3.1, however, which requires a U-factor of 0.074 or lower.

In order to use the criteria in Table 5.5-3, the roof surface must have an emittance equal to or greater than 0.75 and a reflectance equal to or greater than 0.70 or it must have a Solar Reflectance Index (SRI) of 82 or greater.

The roof surface fails on the first count since its emittance is 0.40, which is lower than 0.75. The roof does qualify in terms of its SRI, however. According to Table Table 5-D, for an emittance of 0.40, a minimum reflectance of 0.76 is needed to achieve a SRI of 82.

The roof, therefore, meets the prescriptive requirements.

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Reflectance Index (SRI) of at least 0.82 as calculated by the ASTM E1980 procedure. This procedure considers both emittance and reflectance and rates a surface based on these properties. Table 5-D gives the minimum reflectance needed to achieve an SRI of 82 for values of emittance lower than 0.75.

The largest cool roof benefit is in climate zone 1. In this climate the U-factor criteria for cool roofs are about 29% higher. The criteria are about 20% higher in climate zone 2 and 17% higher in climate zone 3. The benefits of cool roofs are not recognized in climate zones 4 through 8. High reflectance/high emittance surfaces continue to reduce cooling loads in colder climates, but heating performance is adversely affected as useful solar radiation is reflected away. These credits are based on an expected long-term average performance, and they assume degradation of the surface over time from dust, dirt buildup, etc. Note that this exception is not offered for roofs with ventilated attics due to the ventilated space separating the roof surface from the interior. Also, the alternative U-factor criteria are not offered for semiheated spaces or heated only spaces.

Above-Grade Wall Insulation (§ 5.3.1.2)
There are four classes of above-grade walls: mass walls, metal building walls, steel-framed walls, and wood and other walls. Like roofs, the criteria for walls are expressed in two ways. First, minimum R-value criteria are given for the insulation alone. This is the easiest way to comply with the requirement. The alternative is to comply with the U-factor requirement for the overall assembly, including thermal bridges. The U-factor method must be used when one or more of the wall constructions in a class do not comply with the requirement and area-weighted averaging is necessary. The U-factor method may also be appropriate when a wall construction is significantly different from those used to generate the default U-factor tables in Appendix A.

Usually it is very clear if a wall is above grade or not. However, in some cases, a portion of a wall may be above grade and a portion below grade. When a wall is both above grade and below grade and insulated on the interior, the above-grade insulation requirement applies to the entire wall. In this case, a furring strip is typically installed on the inside of the wall and insulation is installed within the cavity of the furring strip. With this construction technique, it is very easy to insulate the entire wall to the above-grade criterion; in fact, it might cost more to reduce the insulation for the below-grade portion. When the insulation is installed on the exterior of the wall or is integral to the wall (for instance, the cells of a concrete masonry wall are filled), then the wall is divided between the above-grade and below-grade portions and the separate requirements apply to each.
A mass wall is a heavyweight wall, generally weighing more than 15 lb/ft² (6.8 kG/m²). The technical definition is that the wall has a heat capacity (HC) greater than 7.0 Btu/ft² ºF for normal density mass materials and 5.0 Btu/ft² ºF for light density mass materials. Mass wall heat capacity is determined from Table A3.1B or A3.1C, as appropriate. See the Reference section of this chapter for more information on heat capacity.

Table 5-E—Single-Rafter Roofs

(This is Table A2.4.2 in the Standard)

	Minimum Insulation R-Value or Maximum Assembly U-Factor		
	Wood Rafter Depth, *d* (actual)		
	2x6	2x8	2x10
Climate Zone	$d \leq 8$ in. ($d \leq 200$ mm)	$8 < d \leq 10$ in. ($200 < d \leq 250$ mm)	$10 < d \leq 12$ in. ($250 < d \leq 300$ mm)
1–7	R-19 (3.3) U-0.055 (0.31)	R-30 (5.3) U-0.036 (0.20)	R-38 (6.7) U-0.028 (0.16)
8	R-21 (3.7) U-0.052 (0.29)	R-30 (5.3) U-0.036 (0.20)	R-38 (6.7) U-0.028 (0.16)

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When the R-value method is used for compliance, the mass wall insulation must be continuous, i.e., the "ci" notation is used with the R-value specification. However, the R-value method can still be used when the insulation is installed with metal Z-clips that are spaced no more frequently than 16 inches on center (o. c.) vertically and 24 inches o. c. horizontally. If other framing (or furring) materials are used, such as wood framing, metal studs, or continuous metal channels, the U-factor compliance method must be used. Furthermore, if insulation were installed so that it is completely continuous (for instance, on the exterior), it would be advantageous to use the U-factor method, since the insulation would be uninterrupted.

For some criteria sets, the mass wall criteria have an asterisk, which indicates that the Exception to A3.1.3.1 applies. This exception permits compliance by insulating the cells of concrete masonry units with any material (such as perlite) that has a thermal conductivity of 0.44 Btu·in./h·ft²·F (0.063 W/m·K) or less. This exception applies only when the concrete masonry units are ungrouted or partly grouted. Partly grouted means that the cells are grouted no more frequently than 32 inches o. c. vertically and 48 inches o. c. horizontally. This exception does not apply to solid grouted walls or concrete masonry walls that do not meet the criteria for ungrouted or partly grouted.

When using the U-factor method, refer to Table A3.1B for solid concrete walls, Table A3.1C for concrete block walls, and Table A3.1D for insulation/framing layers added to these walls. If allowed by § A1.2, Appendix A specifies calculation methods that can be used to determine the U-factor. See the Reference section of this chapter.

Metal Building Walls

When using the R-value criteria for metal building walls, the criteria can be expressed in several ways. When a single R-value is given, for instance "R-13," the requirement can be satisfied by draping batt insulation with the specified thermal resistance over the structural supports (usually horizontal girders). The batt insulation is compressed at the girders. Sometimes, two R-values are given as criteria, for instance "R-13 + R-13." This indicates a double layer of insulation. The first layer is draped over and compressed at the girders, but the second layer is required to be continuous. Figure 5-J shows similar methods of complying with the R-value criteria for metal building walls.

Insulation exposed to the conditioned space or semiheated space must have a facing and all insulation seams must be continuously sealed to provide an uninterrupted air barrier.

When using the U-factor criteria for metal building walls, take values from Table A3.2 of Appendix A of the Standard or, if allowed by § A1.2, use calculation procedures specified in Appendix A. Because of the complexity of heat transfer in metal building walls, Table A3.2 is the only acceptable U-factor available for metal building walls, other than two-dimensional heat flow analysis.

Steel-Framed Walls

If the R-value criteria are given as a single specification, for instance "R-13," this represents the thermal resistance of uncompressed insulation that must be installed in the steel stud cavity. Obviously, it would also be acceptable to use continuous insulation with the specified R-value since the overall thermal performance of the wall would be improved. If there are two values in the R-value specification, for instance "R-13 +

Example 5-E—High Reflectance/High Emittance Roof Surface

Q

A concrete roof in Kuala Lumpur, Malaysia, has a white elastomeric coating applied to the exterior surface that qualifies as a high reflectance/high emittance surface, i.e., its reflectivity is greater than 0.70 and its emittance is greater than 0.75 when tested according to CRRC-1. The primary purpose of the coating is to provide a weatherproof membrane to prevent leaks and deterioration of the insulation, but it also reduces solar gains. The insulation is installed entirely above the deck. What is the minimum R-value needed for compliance?

A

Kuala Lumpur is in climate zone 1 very near the equator and is one of the hottest places in the world. Qualifying cool roofs in this location may use the alternative U-factor criteria in Table 5.5.3.1. The criteria for roof with insulation entirely above deck is 0.082. If the roof surface did not qualify as a cool roof it would have to meet the roof U-factor criterion in Table 5.5-1 which is 0.063.

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R-3.8 ci," the second rated R-value of insulation must be installed in addition to the first and must be continuous (uninterrupted by framing). The notation "ci" stands for "continuous insulation."

The steel-framed construction class includes insulated curtain wall panels. If the U-factor criteria are used, take the data from Table A3.3 or, if allowed by § A1.2, U-factors can be calculated using one of the methods specified in Appendix A. The Reference section of this chapter has details of U-factor calculations, since the techniques apply to both the prescriptive and envelope trade-off options.

Wood and Other Walls

This class of construction includes all wall constructions that do not qualify for one of the other wall classifications. Mainly, however, this class includes walls constructed of wood framing members. Wood studs are generally spaced at either 16 inches o. c. or 24 inches o. c. An exterior sheathing is applied directly to the outer surface of the studs and an interior finish is applied to the inner surface. The thermal performance criterion of wood-framed walls is more stringent because wood is less conductive than metal and provides less thermal bridging when an appropriate level of insulation is installed.

The specification of the R-value criteria is identical to that for steel-framed walls. If a single R-value is specified, for instance "R-13," then insulation with at least this thermal resistance must be installed in an uncompressed manner within the cavity formed by the wood studs. You can also use continuous insulation since this would perform better. When two R-values are specified, for instance "R-13 + R-3.8 ci," the second R-value must be installed as continuous insulation. Usually this means that the insulation is a rigid board and is applied on the exterior of the wall.

When using the U-factor criteria, you can take into account factors in the wall construction that are significantly different from the assumptions underlying the R-value criteria. U-factor data for wood-framed and other walls are contained in Table A3.4 in Appendix A. The Reference section of this chapter has more details.

Below-Grade Wall Insulation (§ 5.5.3.3)

Below-grade walls have conditioned or semiheated space on the inside and earth on the outside. Walls below grade on a sloping site or basement walls are good examples. The criteria for below-grade walls are given either as a minimum R-value for the insulation alone or as a maximum C-factor for the overall assembly. A C-factor is like a U-factor, except that it does not include the interior air film, the exterior air film or the effect of the earth. While the effects of air films and earth were included in establishing the criteria, they have been removed to simplify compliance.

If the R-value method is used for below-grade walls, then insulation with the specified thermal resistance must be installed in a continuous manner with no interruptions by framing members. If framing members interrupt the insulation, then only the *C*-factor method can be used. Insulation for below-grade walls is not required until the heating degree-days exceed 7,200 at base 65ºF (4,000 at base 12ºC).

Often, the same wall may be partly below grade and partly above grade. When this is the case, and when insulation is installed on the interior, the R-value requirement for the above-grade portion applies to the entire wall.

Table A4.2 of Appendix A contains C-factors for below-grade walls. The table has data for three conditions: when insulation is continuous and uninterrupted by insulation, when insulation is installed between metal studs, and when insulation is installed with metal clips. As an alternative to using Table A4.2, and if allowed by § A1.2, C-factors can be calculated using data from Tables A3.1B, A3.1C, and A3.1D. See the Reference section of this chapter for more details.

Floor Insulation (§ 5.5.3.4)

There are three classes of floors in the Standard: mass floors, floors supported by metal joists, and wood-framed and other floors. The floor insulation requirements are expressed as either a minimum R-value for the insulation alone or a maximum U-factor for the overall assembly, including thermal bridges. Compliance can be achieved using either method.

Mass Floors

Mass floors are heavyweight floors, generally greater than 15 lb/ft². The technical definition of a mass floor is that the heat capacity be greater than 7.0 Btu/ft² ·ºF or greater than 5.0 Btu/ft² ·ºF if lightweight concrete is used to construct the floor. When using the R-value method, the insulation must be continuous and uninterrupted by framing members. Insulation sprayed to the underside of a concrete slab qualifies as continuous as long as it also covers structural supports such as steel beams or concrete girders. For waffle slabs, spray-on insulation must cover all surfaces of the waffle in order to be considered continuous. Another method for providing continuous insulation is to place rigid insulation above the concrete slab. This system may have better thermal performance, if the insulation is continuous and not interrupted by columns. Also, this minimizes thermal bridging to interior courtyards or adjacent unconditioned space. In this case, a thin concrete topping slab or a plywood layer is also usually

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provided for attachment of the interior finish floor. When the insulation is not continuous, then the U-factor method must be used. (See Table A5.2 of the Standard's Appendix A.)

Steel-Joist Floors
Steel-joist floors include any floor that is constructed with steel joists, but that does not qualify as a mass floor. If the floor has a heat capacity (HC) large enough to qualify it as a mass floor, then the mass class must be used, even if metal joists support the mass floor. By definition, then, a steel-joist floor has a heat capacity (HC) less than 7.0 if constructed of normal weight concrete. This limits the thickness of normal weight concrete to approximately 2.5 inches.

The steel joists that support the floor can be either open web joists or steel purlins. The key characteristic is that metal framing members interrupt the insulation. When a single R-value is given in the specification, this means that insulation with this thermal resistance must be installed between the joists and is therefore interrupted by the steel joists. Insulation installed in a continuous manner is also acceptable, as is spray-on insulation.

When using the U-factor method, select data from Table A5.3 or, if allowed by § A1.2, calculate your own U-factor using methods defined in Appendix A. See the Reference section of this chapter for details.

Wood-Framed and Other Floors
This class of floor construction includes everything that is not a mass floor or a floor with steel joists. This class mostly includes wood-frame floors. When the R-value method is used and only one R-value is specified, this refers to the thermal resistance of insulation installed between the wood joists. Insulating materials must be installed and supported so that the insulation is in direct contact with the bottom surface of the floor (a mandatory provision).

When using the U-factor method, you must include the overall assembly and any thermal bridging effects. Table A5.4 in Appendix A has data on the U-factor of wood and other floors. See the Reference section of this chapter for details.

Slab-on-Grade Floor Insulation (§ 5.3.1.5)
The Standard has two classes of slabs-on-grade: heated and unheated. Heated slabs-on-grade have hot water pipes or coils embedded within the slab or located beneath the slab to provide space heating. Heat losses from heated slabs are greater because the temperature is warmer. For unheated slabs, insulation is required only for climate zones 7 and 8.

The R-value specification gives both the R-value of the insulation and the depth or width of the insulation. An example is "R-10 at 36 in." This means that insulation with a thermal resistance of 10 must be installed and that the insulation must extend a distance of 36 in. from the top surface of the slab. If the insulation is installed on the inside surface of the concrete foundation wall, the insulation must extend the distance specified or to the top of the foundation, whichever is less. If the insulation is installed outside the foundation wall, it shall extend from the top of the slab directly down for the full distance, or at least down to the bottom of the slab and then horizontally until the specified distance is achieved. For monolithic slab and footing, the insulation must extend only to the bottom of the footing or the distance specified, whichever is less. Figure 5-K gives examples of acceptable and unacceptable slab-on-grade installations.

Table A6.3 of Appendix A has F-factors for various combinations of insulation R-value and insulation depths and configurations. Using this table in conjunction with the F-factor criteria is a flexible way of meeting the requirements.

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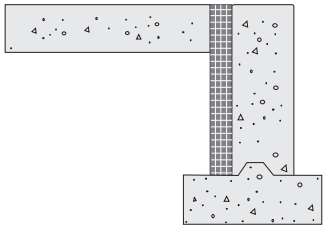
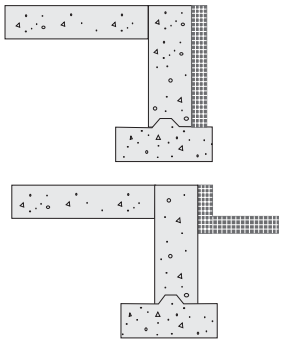
Insulation Inside—Permitted



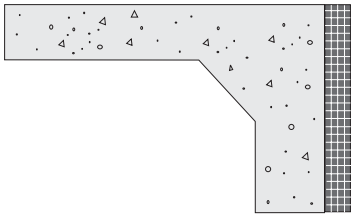
Permitted by Prescriptive and F-Factor Methods

Insulation Outside—Permitted



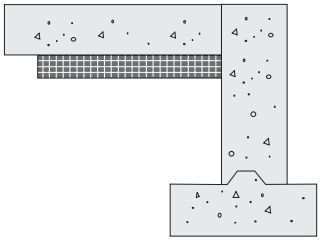
Permitted by Prescriptive and F-Fact or Methods

Monolithic Slab—Permitted



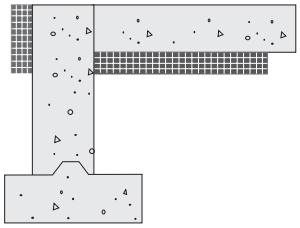
Permitted by Prescriptive And F-Factor Methods

Insulation Beneath Slab—Not permitted



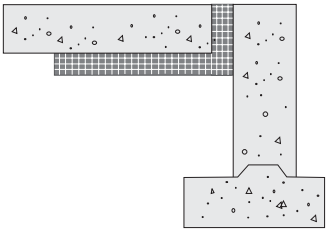
Not Allowed by Prescriptive but the F-Factors are Provided in Table A6.3

Insulation Beneath Slab—Not permitted



Not Permitted

Insulation Beneath Slab—Not permitted



Not Permitted

Figure 5-K—Slab-on-Grade Installations

Opaque Doors (§ 5.5.3.6)
The criteria for opaque doors are expressed only as maximum U-factors. The Standard specifies NFRC ratings for doors in the same way that it does for fenestration. NFRC Standard 100 applies to doors in the same manner that it applies to windows. When doors have NFRC ratings, those U-factors shall be used for compliance. For unlabeled doors, § A7 in Appendix A prescribes the U-factors to use.

Fenestration Criteria (§ 5.5.4)

The fenestration design criteria apply to fenestration, including windows, glass doors, glass block, plastic panels, and skylights. The prescriptive criteria limit the window-wall ratio (WWR) to a maximum of 40% and the skylight-roof ratio (SRR) to a maximum of 5%. For both windows and skylights, there are two performance requirements, a maximum U-factor and a maximum solar heat gain coefficient (SHGC). For skylights, the SHGC criteria depends on the SRR.

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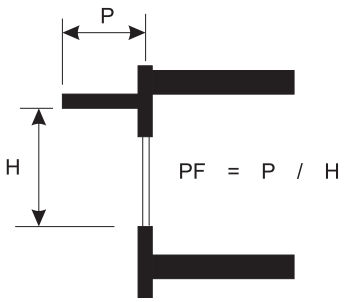

Figure 5-L—Overhang Projection Factor

Vertical Fenestration

There are four classes of vertical fenestration: non-metalic frames, metal frames for curtain walls and storefronts, metal frames for entrance doors, and other metal framed vertical fenestration. Separate U-factor criteria are given for windows in these four classes. The SHGC criteria, however, are the same for all classes.

Maximum Area

The prescriptive requirements allow vertical fenestration areas up to 40% of the gross wall area.

The Standard recognizes the desire for additional glazing at the street level of nonresidential buildings and provides a special allowance for this (see Street-Level Glazing below). Buildings that have vertical fenestration areas greater than 40% must use either the Building Envelope Trade-Off Option or the energy cost budget method.

U-Factor

The U-factor of the fenestration depends on the class (framing type) . For the proposed design, the U-factor must be determined in accordance with NFRC rating procedures (see Mandatory Provisions earlier in this chapter). For products with NFRC ratings, those U-factors must be used. For unlabeled windows, the values in Table A8.2 of Appendix A must be used. When a building has more than one type of window, it is not necessary for every window to meet the U-factor criteria. An area-weighted average calculation can be performed; to show compliance with the Standard, the area-weighted average U-factor must be less than or equal to the criteria.

SHGC

For the proposed design, the SHGC is to be determined in accordance with NFRC rating procedures by a laboratory accredited by NFRC or a similar organization. For products with NFRC ratings, the NFRC rated SHGC must be used. For unlabeled products, the values in Table A8.2 of Appendix A must be used.

Exception (a) to § 5.8.2.5 also allows the shading coefficient of the center of the glass multiplied by 0.86 to be an acceptable alternative to SHGC, if the shading coefficient is determined using a spectral data file determined in accordance with NRFC 300. See the Mandatory Provisions section earlier in this chapter for details. In addition, exception (b) permits the SHGC for the center-of-glass to be used for compliance calculations.

Visible Light Transmittance (VLT)

There are no minimum VLT requirements in the Prescriptive Building Envelope Option. There are, however, minimum criteria in the Building Envelope Trade-Off Option.

Table 5-F—SHGC Multipliers for Permanent Projections

(This is Table 5.5.4.4.1 in the Standard)

Projection Factor	SHGC Multiplier (All Orientations)	SHGC Multiplier (North-Oriented)
0 - 0.10	1.00	1.00
<0.10 - 0.20	0.91	0.95
<0.20 - 0.30	0.82	0.91
<0.30 - 0.40	0.74	0.87
<0.40 - 0.50	0.67	0.84
<0.50 - 0.60	0.61	0.81
<0.60 - 0.70	0.56	0.78
<0.70 - 0.80	0.51	0.76
<0.80 - 0.90	0.47	0.75
<0.90 - 1.00	0.44	0.73

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Example 5-F—Fenestration Criteria, Building with Overhangs

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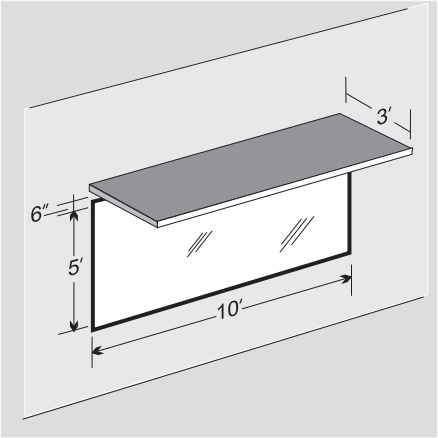
A travel agency under design in Fayetteville, Arkansas, has typical windows on all sides of the building as shown in the figure below. The window-wall ratio is 32%. Each window is 5 ft high and 10 ft wide, has an overhang that projects 3 ft from the surface of the glass, and is positioned 6 in. above the window head. The window has an NFRC rating and label. The NFRC-rated solar heat gain coefficient (SHGC) is 0.6. Does the building comply with the nonresidential SHGC fenestration criteria of the Standard?



A

The appropriate criteria table for Fayetteville is Table 5.5-4. This is determined by locating Fayetteville in Figure 5-E. From Table 5.5-4, the SHGC criterion is 0.40.

The windows in this building qualify for an overhang credit. The first step in determining the credit is to calculate the overhang projection factor (PF), which is the ratio of the 3 ft projection to the distance from the windowsill to the bottom of the overhang (5.5 ft). PF is then 3 / 5.5 = .54. Reading from Table 5-F, the overhang multiplier is 0.61 for non-north orientations and 0.81 for north orientations. The effective SHGC on non-north orientations is 0.61 × 0.6 = 0.37. The effective SHGC on the north orientation is 0.81 × 0.6 = 0.49. In this case, the non-north windows comply, but the north-facing windows do not.

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Overhangs

Overhangs can reduce solar gains through windows. The Standard allows credit for overhangs that provide significant shading. Overhangs must be a permanent part of the building before credits can be applied. The Standard credits overhangs by allowing an adjustment to the SHGC when overhangs exist. Table 5-F (Table 5.5.4.4.1 in the Standard) has multipliers that reduce the SHGC when overhangs are present.

The size of the overhang is determined by the projection factor, which is the ratio of the overhang projection to the distance from the window sill to the bottom of the overhang (see Figure 5-L). The overhang projection is measured from the surface of the glass to the outer edge of the overhang.

Conventional overhangs are solid, however, the Standard also offers credit for louvered overhangs and overhangs made of transparent or translucent materials such as tinted or fretted glass.

Credit for translucent overhangs is determined based on the average opacity of the overhang (a solid overhang is 100 percent opaque). The average opacity of translucent overhangs is calculated using the equation below.

$$O_s = (A_i \times O_i) + (A_f \times O_f) \quad (5\text{-A})$$

where

O_s = Opacity of the shading device

O_i = Opacity of the transluscent infill. This is calculated as one minus the solar transmittance of the glass

O_s = Opacity of the framing (generally unity)

A_i = Percent area of the infill.

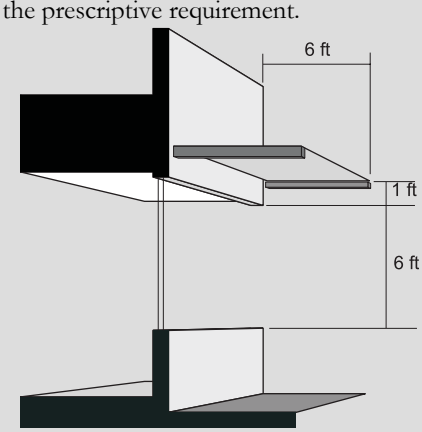
A_s = Percent area of the framing.

Once the opacity is calculated, it is multipled times the projection factor to determine the adjusted projection factor. This adjusted projection factor is then

Example 5-G—Translucent Overhang Credit

Q

An Atlanta office building proposes to use continuous glass overhangs on the south facades supported by welded steel tubes. The overhang projects from the building 6 feet and is positioned 1 ft above the window head. The glass in the overhang structure has a center of solar transmission of 0.30. The window is 6 feet high and is rated by NFRC to have a SHGC of 0.40. The steel tubes are 4 in. wide and 6 in. deep. And are spaced 4 ft apart (on center). The SHGC criteria for Atlanta is 0.25. Does the proposed window with its overhang meet the prescriptive requirement.



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The overhang has a projection factor of 0.86 (the overhang projection of 6 ft divided by the 7 ft distance from the window sill to the bottom of the overhang). The percent of opaque overhang framing is 8.3% (4 in. of framing divided by 48 in. of center-to-center width), leaving the percent of glass at 91.7%. The opacity of the overhang is 0.725 as calculated below. This adjusted projection factor is 0.62, also calculated below. The SHGC multiplier is 0.56, reading from Table 5.5.4.4.1. This results in an adjusted SHGC for the shaded window of 0.22, which complies with the criteria of 0.25.

$$PF = \frac{6}{1+6} = 0.857$$

$$O_s = (A_i \times O_i) + (A_f \times O_f)$$

$$= (0.917 \times (1 - 0.30)) + (0.083 \times 1.0) = 0.642 + 0.083 = 0.725$$

$$PF_{Adj} = PF \times O_s = 0.857 \times 0.725 = 0.621$$

$$M = 0.56 \text{ (From Table 5.5.4.4.1)}$$

$$SHGC_{Adj} = SHGC \times M = 0.40 \times 0.56 = 0.22$$

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used to enter table 5.5.4.4.1 to get the SHGC multiplier. See Example 5-G.

Credit is offered for louvered overhangs only when the the louvers are angled and spaced such that no direct sunlight passes through the louvers at solar noon on the summer solstice (June 21 in the northern hemisphere).

Tools such as the Sun Angle Calculator may be used to determine the position of the sun at solar noon and at other times.

A concept that is useful in making this determination is the profile angle. The profile angle is the angle between a normal from the window or surface and the altitude angle of the sun looking in the direction of the normal.
For south facing windows, the altitude of the sun at noon is equal to the profile angle. For other window orientations, the profile angle can be determined using the Sun Angle Calculator, reference tables or other appropriate tools.

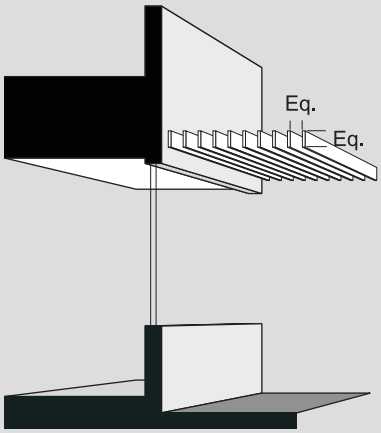
Street-Level Glazing
Tenants in retail and other ground-level spaces often want to use clear glass. The Standard has an exception to the SHGC criteria for windows that are located at the street level of nonresidential buildings. Untinted glass is permitted when all the following requirements are satisfied. Figure 5-M illustrates these requirements.

- The street side of the street-level story does not exceed 20 ft (6 m) in height. This requirement does not apply to tall spaces such as multi-story atriums.
- The fenestration has a continuous overhang with a weighted average projection factor greater than 0.5. This overhang provides shading to partially compensate for the SHGC exception.
- The fenestration area for the street-side of the street-level story is less than 75% of the gross wall area for the street-side of the street-level story. This

Example 5-H—Louvered Overhang Credit

Q

A Fresno, California office building proposes to use louvered overhangs on the south side of the buildings to provide shade for the windows. The louvers are positioned vertically and the space between them is equal to the height of the louvers. Is such an overhang credited by the Standard.



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Louvered overhangs are credited as long as they block the sun at noon on the summer solstice. Fresno is located at 36.77 degrees north latitude. At noon on the summer solstice, the sun has an altitude of 77 degrees. The cut off angle of the louvers is only 45 degrees, so there would be sun penetration through the louvers and the overhang could not be credited.

Example 5-I—Louvered Overhang Credit

Q

A designer of a building at north latitude 40 degrees wants to use louvered overhangs to shade a window that faces southeast. What is the cutoff angle needed in order for the louvers to be credited by the Standard. The louvers are oriented parallel to the window.

A

The profile angle for a southeast facing window at 40 degrees north latitude at noon on the summer solstice is 78 degrees. The louvers would have to be spaced such that the sun would not penetrate at this angle.

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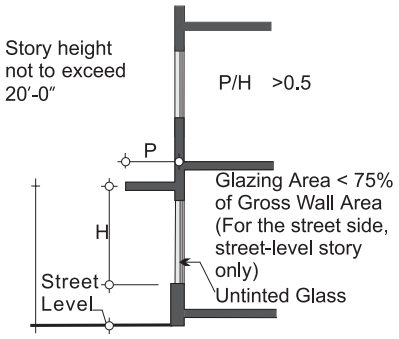

Figure 5-M—Vertical Fenestration at Street Level

exception does not apply to sides of the building that do not face the street.

Note that when this exception is used, these areas shall be calculated separately and not averaged with any others. No glazing area can be credited or used elsewhere in the building, even if the full 75% allowance is not used. Also, this exception only applies when using the prescriptive compliance option. This exception does not apply to the Building Envelope Trade-Off Option in § 5.6 or to the energy cost budget method in § 11.

Also, be aware that this exception is limited to the SHGC criteria. The fenestration must still comply with the U-factor criteria. Clear low-e coatings can be used to comply with the U-factor while still providing good visibility for store windows.

Skylights

There are three classes of skylights: glass skylights with a curb, plastic skylights with a curb, and any type of skylight without a curb (which are mostly glass). For each skylight class, the criteria also depend on the skylight area. The larger the area, the more stringent the criteria are. As with windows, the skylight-roof ratio must be calculated separately for each space category. The criteria for each space category are determined from its own skylight-roof ratio, not the skylight-roof ratio for the whole building.

Example 5-J—Prescriptive Building Envelope Option, Seattle Waterfront Restaurant

Q

A restaurant is being designed for a location in Seattle, Washington, which has good views across Puget Sound to the Olympic Mountains. The wood-framed building will be insulated to comply with the Standard. The schematic design has the west facade almost entirely glazed, but there aren't many windows in the other walls so the overall fenestration area is 37% of the gross exterior wall area. For greater comfort for the diners, the picture windows are wood-framed and double-glazed with a low-e coating on the third surface. The windows are manufactured locally and are NFRC rated with a U-factor of 0.52 and an SHGC of 0.55. The glass is clear and there are no overhangs. Will this comply with the Standard or are modifications necessary?

A

The envelope criteria set for Seattle is Table 5.5-5. For the nonresidential space category (a restaurant belongs to this category), the vertical fenestration criteria call for a U-factor of 0.35 for a nonmetallic frame. The maximum SHGC is 0.40for all orientations.

The building fails to comply with both the U-factor criteria and the SHGC criteria. The designer has a couple of choices for compliance. Another glazing material can be selected that has a U-factor less than 0.35 and a SHGC less than 0.40.

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Maximum Area
With the Prescriptive Building Envelope Option, skylight area is limited to a maximum of 5% of the gross roof area. This limit applies separately to each space category in the building. Buildings that have a skylight-roof ratio greater than 5% must use the Building Envelope Trade-Off Option or the energy cost budget method.

U-Factor
The maximum U-factor depends on the skylight class. If NFRC ratings are available for the skylight, then the NFRC U-factor must be used. For unlabeled skylights, take the U-factor of the proposed design from Table A8.1A of Appendix A of the Standard.

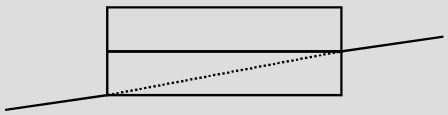
SHGC
The maximum SHGC depends on the skylight class. If the skylight has an NFRC rating, then that value must be used. For unlabeled skylights, Table A8.1B of Appendix A has values that are to be used. Alternatively, you can obtain manufacturer's shading coefficient data for the glazing used in the skylight and use 86% of this value as the SHGC, provided that the shading coefficient is established using a spectral data file determined in accordance with NFRC 300 (see exception (a) to § 5.8.2.1).

Visible Light Transmittance (VLT)
There are no minimum VLT requirements in the Prescriptive Building Envelope Option. There are, however, minimum criteria in the Building Envelope Trade-Off Option.

Example 5-K—Determining Gross Wall Area

Q

A building in Nashville is sited on a sloping site such that the first floor of the north wall is below grade. The first floor of the east and west walls are partially below grade, as the ground slopes. The building is rectangular in shape with a 200 ft dimension in the east-west direction and a 100 ft dimension in the north-south direction. The floor-to-floor height is 12 ft. What is the gross wall area for this building? This is significant since the maximum allowable window area requirement is based on the WWR.



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The gross wall area includes both above-grade walls and below-grade walls so that gross wall area is simply the perimeter of the building (200 + 100 + 200 + 100) times the 24 ft height or 14,400 ft².

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Example 5-L—Prescriptive Building Envelope Option, Tucson Supermarket

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A proposed 20,000 ft^2 supermarket in Tucson, Arizona, has its entire glazing oriented south in one wall facing the street. The initial design is for clear, single glazing so that shoppers can easily see all the products inside. Clear glass has an SHGC of 0.82. The building has no overhangs. The fenestration area is 17% of the gross exterior wall area. The walls are 8 in. normal weight concrete block and the ungrouted cores are filled with insulation. Will this comply with the Standard or are modifications necessary?

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The envelope criteria table for Tucson is 5.5-2 (see Appendix B, Pima County). For the nonresidential space category, the mass wall U-factor criteria is 0.15 or R-5.7 continuous insulation or insulation in the cores (Exception to Section A3.1.3.1 applies)so the CMU walls comply. The criteria for vertical fenestration limit the U-factor to a maximum of 0.60 for a metal framed curtain wall. The SHGC criterion is 0.25. The proposed single glass does not meet the U-factor criterion nor does the SHGC of 0.82 meet the 0.25 criterion .

The designer has several choices for compliance. One is to select a glazing material that meets the 0.25 SHGC criterion and the 0.60 U-factor criterion. . The problem is that most products that have an SHGC this low are too opaque. Another option is to take advantage of the exception for street-level glazing. Exception (c) to § 5.4.4.4.1 exempts glazing from the SHGC criterion provided that an overhang is provided that has a projection factor of at least 0.5, the floor-to-floor height at the street level does not exceed 20 ft, and the exempt fenestration does not exceed 75% of the street-level façade. Using this exception, the clear glass can be used in the intended application. However, a clear glass would have to be selected that meets the U-factor criterion and the mass walls would have to be insulated.

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Trade-Off Option (§ 5.6)

Section 5.6 and Appendix C of the Standard cover the Building Envelope Trade-Off Option. With the trade-off option, the performance of one envelope component can be improved to make up for another component that may not meet the Standard. While area-weighted averaging allows these types of trade-offs to be made within a single class of construction, the trade-off option permits similar trade-offs between all envelope components. The Building Envelope Trade-Off Option involves a little more work because it is necessary to measure all the surface areas and to tabulate the wall areas by orientation. However, it does provide considerable design flexibility, beyond what is offered by the Prescriptive Building Envelope Option. This flexibility is often extremely important; it helps designers respond to a building's unique characteristics, including different user needs, a different site, and often a different climate.

There are times when the Building Envelope Trade-Off Option *must* be used, for instance, when vertical fenestration exceeds 40% of the gross wall area or when the total skylight area exceeds more than 5% of the roof area. The Building Envelope Trade-Off Option cannot be used to make trade-offs between the building envelope and the lighting or mechanical systems.

EnvStd Program

The method used to make the trade-offs is documented in Appendix C of the Standard. The method consists of a series of equations that result in a figure of merit called the envelope performance factor (EPF). EPF is a relative term that approximates the total heating and cooling energy associated with a single square foot of surface. The equations in Appendix C were developed from computer simulations using DOE-2. Some of the equations, especially those for walls, will appear complex. However, the equations have all been incorporated in the EnvStd computer program included with this Manual. This program is easy to use and can be a helpful tool in early design phases as well. Because of the complexity of the procedure documented in Appendix C, it is strongly recommended that compliance be shown using the EnvStd program. Consequently, the discussion that follows is geared to the EnvStd program. The EnvStd software is not part of the Standard—only the procedure is. This enables new features to be added to the program, as long as they use the methods and procedures documented in Appendix C.

Daylighting Potential

When using the EnvStd computer program, you must specify the U-factor, SHGC, and VLT for windows and skylights (for the Prescriptive Building Envelope Option, it is only necessary to know the U-factor and SHGC; the VLT is not used). The VLT is used in EnvStd to determine a daylighting potential term that could be either a benefit or a detriment. A benefit will result when the glazing used in the proposed design has a high VLT. A penalty will result when glazing used in the proposed design has a low VLT. The daylighting potential EPF term provides a modest incentive to choose glazing products that have a high VLT. Even though a building may not have daylighting controls installed, if a daylighting potential exists, building users have the potential to save energy by manually turning off the lights.

Furthermore, the building fenestration usually lasts for the life of the building and is rarely modified. Lighting systems, on the other hand, are frequently modified and even replaced. As the cost of automatic daylighting controls continues to decline (in real terms), it is likely that in future building renovations, automatic daylighting controls will be installed and even more daylighting energy savings will be realized.

Limits of the EnvStd Program

EnvStd cannot be used to bypass any of the Standard's mandatory requirements. Furthermore, EnvStd cannot be used to make trade-offs between the building envelope and the lighting or mechanical systems. The energy cost budget method must be used to make envelope trade-offs against lighting or HVAC improvements.

Using the EnvStd Computer Program

To use the EnvStd computer program, insert the CD that is included with this Manual in your computer (the program works with Windows™ NT/XP/Vista operating systems). Run the program called Setup.exe to install EnvStd in the directory of your choice. The program has its own electronic help system and program documentation, so the details about how to use the program are not repeated here. Instead, the following example demonstrates how the program works and when its use is appropriate.

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Example 5-M—EnvStd Program, Retail Showroom/Warehouse Mixed-Use, Omaha, Nebraska

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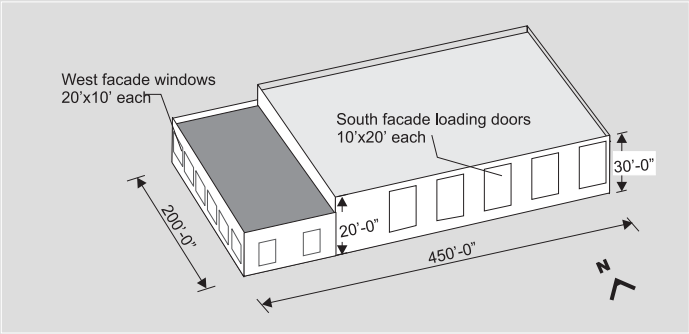
Design is nearing completion on a 90,000 ft², single-story building just south of Omaha, Nebraska. The building is 25% retail showroom and 75% warehouse. The building is 200 ft by 450 ft with the long axis running east-west. The showroom is on the west end of the building as shown in the sketch below. The exterior wall height is 20 ft at the showroom and 30 ft at the warehouse. The walls of the warehouse and the showroom are constructed of solid concrete (tilt-up) with an interior furring space with R-11 insulation.

Vertical fenestration is located only in the showroom. The west façade has six windows, each measuring 20 ft wide by 10 ft high for a total of 1,200 ft^2 of fenestration. Both the south and north sides of the showroom have two windows also 10x20 ft. The fenestration has an NFRC rated U-factor of 0.45, an SHGC of 0.40 and a light transmission of 0.50.

There are five loading doors on the south side of the building. Each is 20 ft wide by 10 ft high and is insulated with a tested U-factor for the entire door (not just the insulated section) of 0.14.

The building's walls are 8 inch-thick concrete, built using the tilt-up construction technique. The walls of the building's sales area are insulated with R-13 on the inside. The insulation is supported by metal clips installed at 24 inches on center. The concrete walls in the warehouse portion of the building are not insulated. The roofs of both the sales area and the warehouse are insulated with R-15 rigid foam installed entirely above the structural deck.



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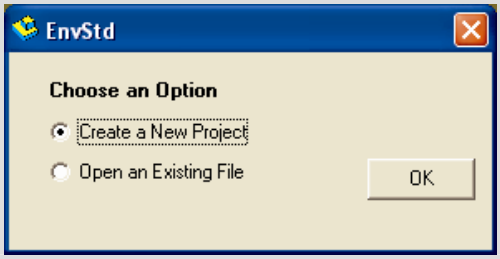
Step 1:
Start the Program

For this example, it is assumed that you have correctly installed the EnvStd 6.0 computer program. When you start the program, you are given a choice of starting a new project or opening an existing file. For this example, select the CREATE A NEW PROJECT radio button and click the OK button.



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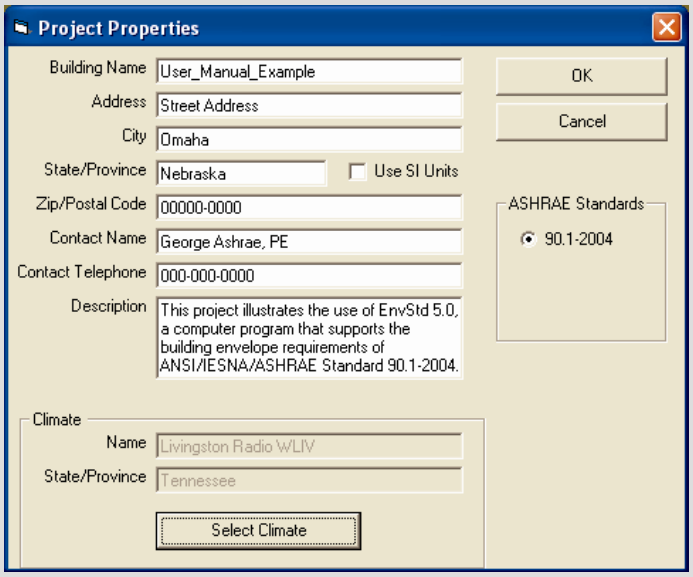
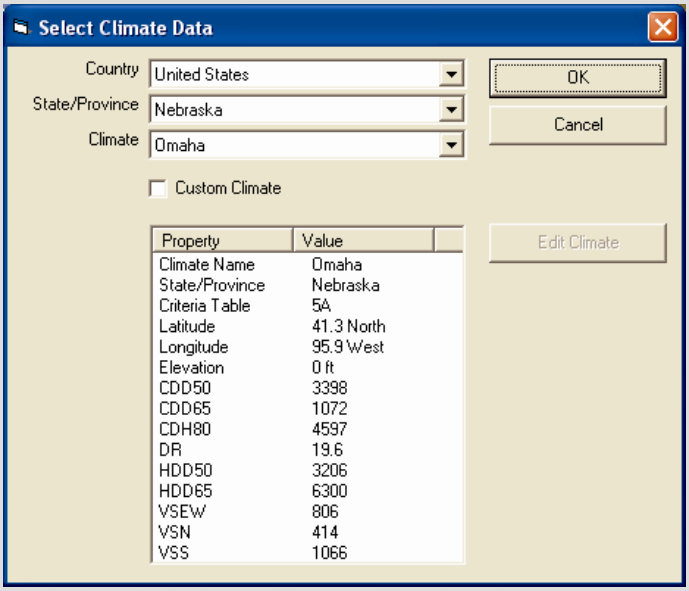
Step 2:
Project Properties
The program will then automatically open the Project Properties form where you enter general information about the building for which you are determining compliance. You enter a name for your project, its address, and an optional description. You also enter the name and telephone number of the person that should be contacted if there are questions about the project or the data that was entered. Indicate if you want to use metric (SI) units or inch-pound (I-P) units. To use SI units make sure that check box labeled USE SI UNITS is checked. Leave this unchecked to use inch-pound units. In this example, the designers in Omaha are more familiar with I-P units, so the box is left unchecked. To choose a climate location, click the SELECT CLIMATE button.



Choose the climate location for the project by selecting a country, state and climate, in that order. When you choose a country (either U.S. or Canada), the states or provinces for that country are displayed in the State/Province list box. When you choose a state or province, the climates for that state or province are displayed in the Climate list box. Select a climate from the available choices. Two things happen when you choose a climate: weather variables for that location are read from the library and the design criteria for that location is established. When you choose a state and climate, the City and State text boxes are filled automatically, but you can overwrite this data if you want.



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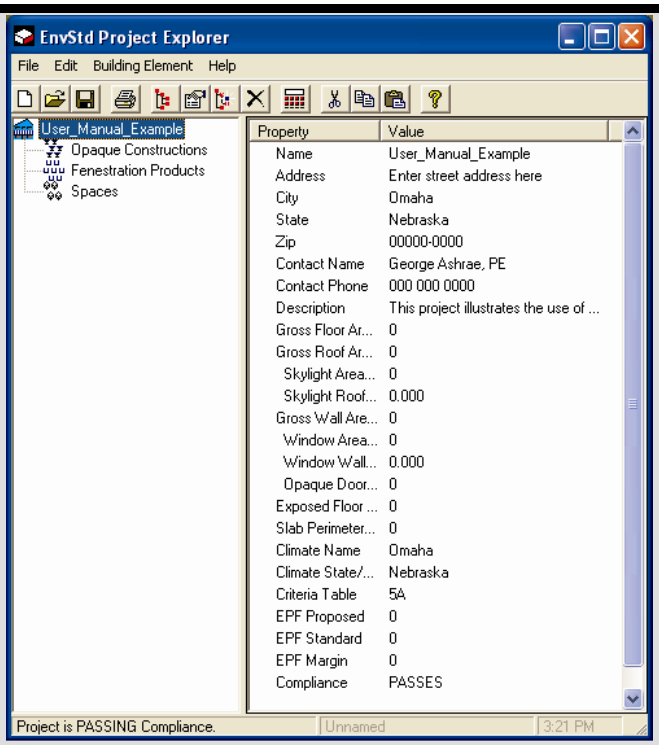
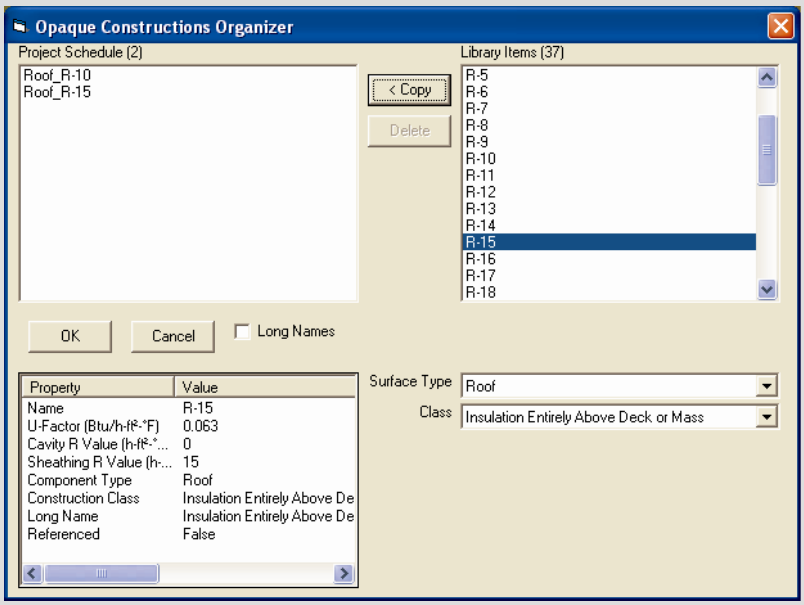


Step 3:
The Project Explorer

Click the OK button in Project Properties to accept the data you entered. The Project Properties window will then close and the Project Explorer form will be displayed. This is the program's main form. The left side of the form shows all the building components in a hierarchical manner, with the building object—identified by the name you gave the project in step 2—appearing as the root at the top. When you select an object on the left side of the form, the object's properties appear on the right side of the form. In this example, the building object "User_Manual_Example" is selected, and the building object's properties that you entered in step 2 appear on the right side of the form. To edit an object (e.g., to change the address, city or climate data), select the object and then click the Properties button on the tool bar.



Step 4:
Create the Opaque Constructions Schedule

Highlight Opaque Constructions and click on the Properties button. You can add to the Opaque Constructions collection in two ways. The easiest method is to use pre-calculated U-factors from Appendix A of the Standard. Alternatively, you can enter your own performance data, essentially creating your own opaque construction or fenestration product. However, the Standard requires that you use opaque construction data from Appendix A when reasonable matches exist.

All the constructions from the Appendix A library appears on the right side of the Opaque Constructions Organizer window. The left side of the form shows any constructions that have been added to the project schedule. To add a construction from the library to the schedule, highlight a row in the Library Items list on the right of the form and click the COPY button. This will place a copy of the library opaque construction in the project schedule.

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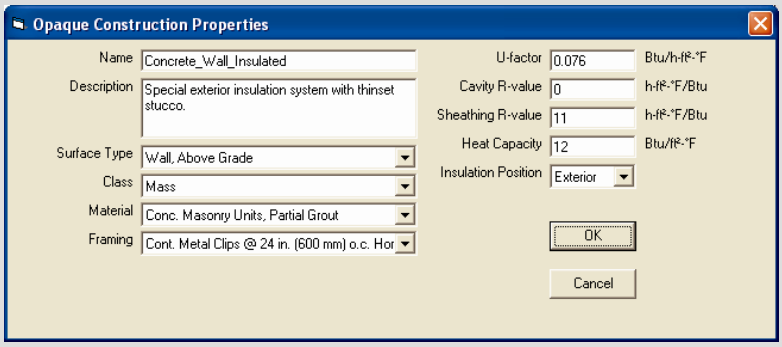
The library of constructions from Appendix A is quite large, with almost 3,000 entries. Usually you will want to limit the choices you are viewing. Use the SURFACE TYPE and CLASS drop-down list boxes to filter the list. Each time you make a choice from these list boxes, the lists will be filtered to show only the choices for that component, class or category.

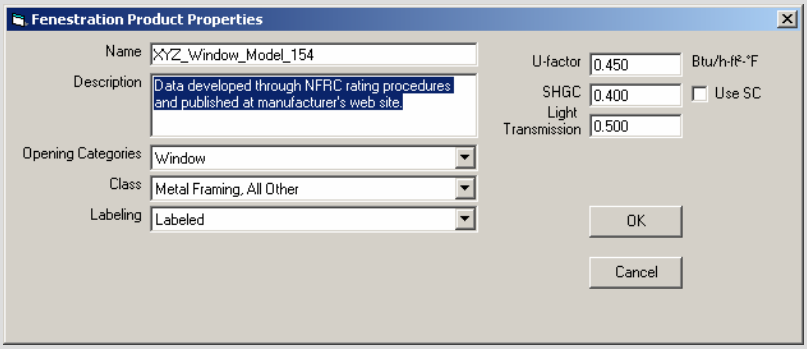


The construction names are short, and unless you have filtered the list, it may be difficult to tell one construction from another (for example, several constructions may be called R-11). To see more detail about a construction, click the "Long Names" checkbox and the names will be displayed with the name of the surface type, the class and other details.

Continue working in the Opaque Constructions organizer until you have completed the schedules. For the example building, create a roof construction with R-15 installed entirely over the structural deck, a partially grouted wall construction, and a slab construction.

The concept of schedules should be familiar to most architects and engineers since the same concept is used to organize construction drawings.

If the construction you need is not in the library, then you can enter the data yourself. To do this, choose the Opaque Constructions collection on the left side of the Project Explorer form and click the button (Add Child). A new opaque construction will be created and the Opaque Construction Properties form will appear so that you can define its properties. *Standard 90.1-2007* only allows you to enter your own data if Appendix A does not have a reasonable entry already calculated.



Step 5:
Create the Fenestration Products Schedule

The next step is to add fenestration products to the project schedule. This process is similar to the one used to create the collection of Opaque Constructions, except that the library of constructions is not as long. For opaque constructions, the Standard encourages use of the default U-factors in Appendix. However, for fenestration products, the Standard encourages the use of NFRC (National Fenestration Rating Council) ratings.

These data are not included in Appendix A since the data vary from manufacturer to manufacturer and frequently change. Except for skylights, the Standard encourages NFRC ratings for compliance purposes, since the default values do not offer much credit. This means that the Fenestration Products library is less important. Most of the time you will need to obtain data from the manufacturer for the specific products you are using in your project.

To add a fenestration product, choose the Fenestration Products collection in the Project Explorer and click the Add Child button. A form appears for defining the properties of the fenestration product. The critical performance characteristics are the U-factor, the light transmission and the solar heat gain coefficient (SHGC). These data are available from NFRC tests.

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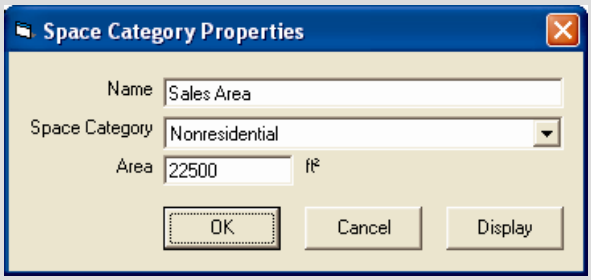
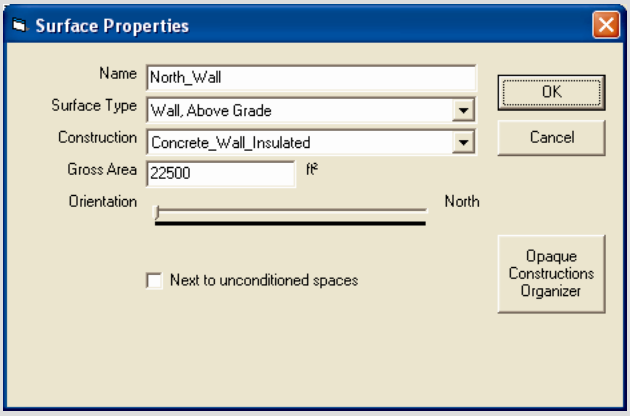


Step 6:
Add the Spaces

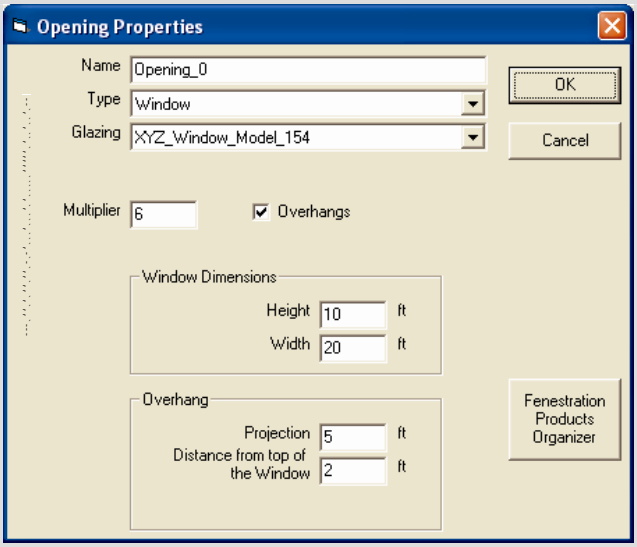
Now that the project has a schedule of opaque constructions and fenestration products, you can enter geometric information about the building. The schedules must be populated before geometric information (i.e., surfaces) can be entered. The example building has both conditioned space and semiheated space. This means that two spaces must be entered. To enter a space, select the Spaces collection in the Project Explorer (on the left side of the form) and click the Add Child button.

This action launches a form, where you enter the properties of the space. Only three properties are applicable: a user-defined name, the space category that must be selected from a drop-down list box (the choices are nonresidential, residential, and semiheated), and the floor area of the space. For the example building, add two spaces—a nonresidential space of 22,500 ft² and a semiheated space of 67,500 ft².



Step 7:
Add Surfaces

Once the spaces have been added to the Project Explorer, the next step is to add the surfaces that surround each of the spaces. In the example building, both the sales and warehouse portion of the building each have one roof, three walls, and a slab. To add a surface, choose the appropriate space and click the Add Child button. A form appears enabling you to define the properties of each of the surfaces. The same form is used for all surfaces, but for walls an additional control appears where you specify the orientation. For walls and roofs, enter the gross area (including openings). Choose a construction from the choices in the opaque constructions schedule.



Step 8:
Add Openings

Some of the walls have openings. To add an opening to a wall, select the wall and click the Add Child button. This launches a form where you define the properties of each opening. Repeat this process until each opening has been defined.

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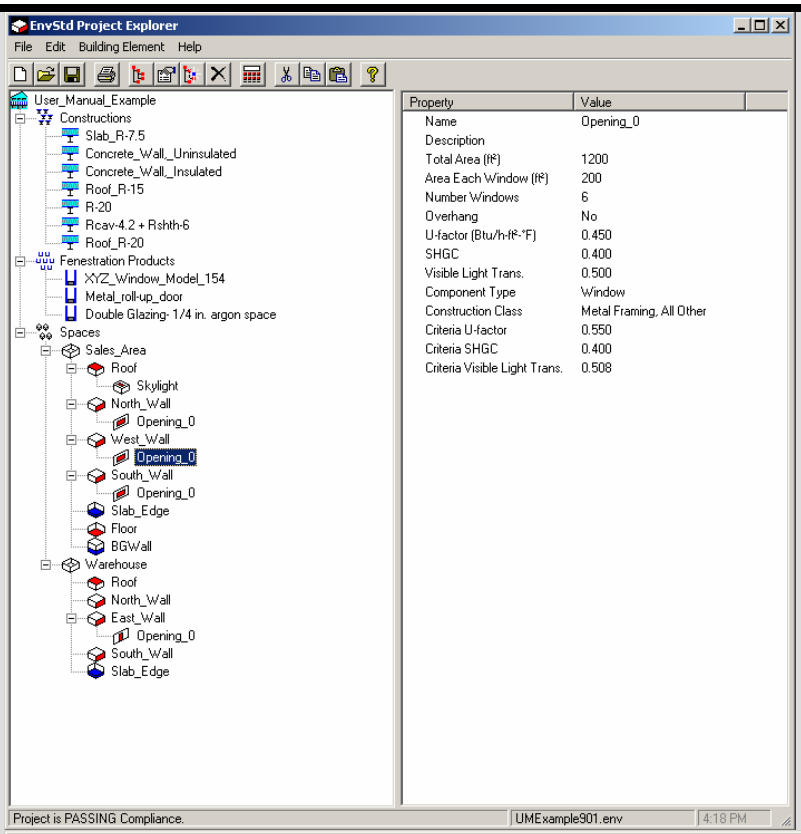
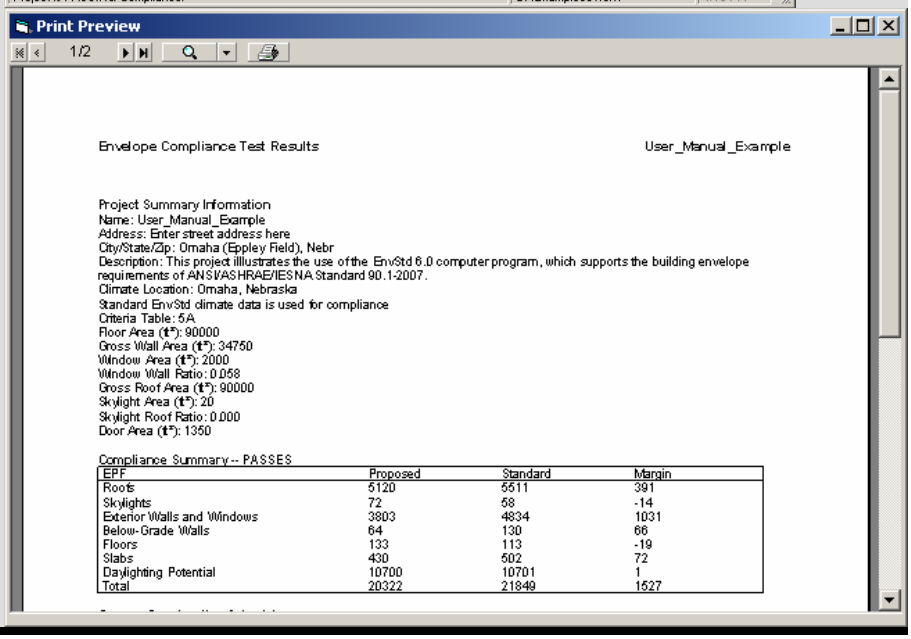
Step 9:
Project Explorer
Once all the detail has been added to the project, the Project Explorer should look like the following EnvStd Project Explorer form if all the nodes (i.e., Constructions, Fenestration Products and Spaces) are expanded. Note that the status bar at the bottom of the form tells you if the project is complying with the Standard (in this example it is). Each time you add or modify a building envelope component, compliance is recalculated and the status bar is updated.



Step 10:
View/Print Reports
Once you have correctly entered the building, you can view and print the compliance reports. To do this, click the Print button. The Print Preview window will be displayed, allowing you to review the results of the calculation. The compliance report can be printed and attached to your building permit application to demonstrate that the project complies with the building envelope requirements of ANSI/ASHRAE/IESNA *Standard 90.1-2007*.


Print Preview
1/2
Envelope Compliance Test Results
User_Manual_Example
Project Summary Information
Name: User_Manual_Example
Address: Enter street address here
City/State/Zip: Omaha (Eppley Field), Nebr
Description: This project illustrates the use of the EnvStd 6.0 computer program, which supports the building envelope requirements of ANSI/ASHRAE/IESNA Standard 90.1-2007.
Climate Location: Omaha, Nebraska
Standard EnvStd climate data is used for compliance
Criteria Table: 5A
Floor Area (ft²): 90000
Gross Wall Area (ft²): 34750
Window Area (ft²): 2000
Window Wall Ratio: 0.058
Gross Roof Area (ft²): 90000
Skylight Area (ft²): 20
Skylight Roof Ratio: 0.000
Door Area (ft²): 1350
Compliance Summary -- PASSES
EPF | Proposed | Standard | Margin
Roofs | 5120 | 5511 | 391
Skylights | 72 | 58 | -14
Exterior Walls and Windows | 3803 | 4834 | 1031
Below-Grade Walls | 64 | 130 | 66
Floors | 133 | 113 | -19
Slabs | 430 | 502 | 72
Daylighting Potential | 10700 | 10701 | 1
Total | 20322 | 21849 | 1527

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Reference

General Concepts
Exterior Loads
Internal Loads
Residential Space Category
Nonresidential Space Category
Conditioned Space
Semiheated Space
Unconditioned Space
Exterior Envelope
Semi-Exterior Envelope
Area-Weighted Averages

Fenestration
Window-Wall Ratio
Skylight-Roof Ratio
Fenestration U-factor
Solar Heat Gain Coefficient (SHGC)
Shading Coefficient (SC)
Interior Fenestration Shading
Exterior Fenestration Shading
Visible Light Transmittance (VLT)
Projection Factor (PF)
Vertical Fenestration Classes
Skylight Classes

Opaque Surfaces
U-Factor
R-Value
Heat Capacity (HC)
Solar Reflectance
Emittance
Acceptable Calculation Methods
Roof Classes
Above-Grade Wall Classes
Below-Grade Wall Classes
Floor Classes
Slab-on-Grade Floor Classes
Opaque Door Classes

General Concepts

There are a number of concepts and definitions that are key to understanding the building envelope requirements. These are discussed in this Reference section. This section presents definitions, concepts, reference materials, and calculation methods that are common to both the Prescriptive Building Envelope Option and the Building Envelope Trade-Off Option. The reference material is organized by the following topics:

Exterior Loads

Exterior loads include solar gains through windows, conduction losses due to temperature differences across envelope surfaces, and air leakage (infiltration). Exterior loads are dynamic. They change as outdoor temperatures change, as the sun moves through the sky, and as wind changes speed and direction. The building's envelope design directly affects the magnitude and time pattern of exterior loads. Solar gains can be controlled by correctly oriented and shaded windows and by glazing that limits solar gain while transmitting visible light; conduction loads can be reduced by effective insulation; and infiltration can be controlled by careful caulking and weather-stripping.

Internal Loads

Internal loads are heat gains from lights, equipment and people. They consist of both sensible gains (elevated air temperatures) and latent gains (moisture added to the space). Lighting and most electrical equipment produce only sensible gains, while people and outdoor air ventilation produce both sensible and latent loads. Cooking equipment can produce both sensible and latent gains.

For the most part, internal loads are the result of the way the building is used, not the design of the envelope. An exception is the need for electric lighting, which can be reduced if the envelope is designed to introduce useful daylight into the building. Even though the envelope design has more of an effect on controlling exterior loads than internal loads, the building envelope designer should consider internal gains. Buildings with high internal loads have larger cooling loads and smaller heating loads, while buildings with low internal loads have higher heating loads and smaller cooling loads. The designer should know which is more important, reducing heating or cooling loads. These factors were taken into account in the development of the Standard's envelope requirements.

Many commercial buildings have internal gains so high during occupied periods that the building needs to reject heat for all but the coldest outdoor conditions. Heating may only be necessary for morning warm-up or times when the building both has low internal loads and solar gain is not available. On the other hand, warehouses and high-rise residential buildings usually have low internal gains, so outside temperature and solar gains are more important.

The Standard recognizes three space conditioning categories: nonresidential, residential, and semiheated (see also Space Conditioning Categories in the General Information section of this chapter). The building envelope requirements that apply depend on the space conditioning category that a surface or opening encloses. The nonresidential and residential space categories are both conditioned, that is, they are heated (and possibly cooled) for the purposes of maintaining human comfort. Conditioned space is defined in greater detail below.

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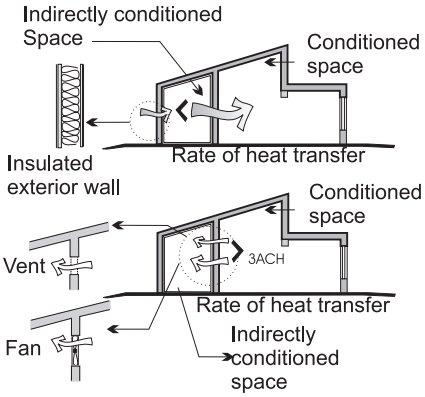

Figure 5-N—Examples of Indirectly Conditioned Spaces

Residential Space Category
The residential space category includes, but is not limited to, conditioned space for dwelling units, hotel/motel guest rooms, dormitories, nursing homes, patient rooms in hospitals, lodging houses, fraternity/sorority houses, hostels, prisons, and fire stations. Residential spaces are conditioned on a more-or-less continuous basis. The requirements for residential spaces are a little more stringent than for nonresidential spaces, since more can be invested in energy efficiency if the space is heated and cooled for a longer period. Spaces that are not conditioned (see Unconditioned Space) are considered semiheated or unconditioned.

Table 5-G—Heated Space Criteria

(This is Table 3.1 in the Standard)

Heating Output (Btu/h·ft²)	*Climate Zone*
5	1 and 2
10	3
15	4 and 5
20	6 and 7
25	8

Nonresidential Space Category
The nonresidential space category includes all other conditioned spaces covered by the Standard including, but not limited to, offices, retail shops, shopping malls, theaters, restaurants, meeting rooms, etc. The key feature of nonresidential spaces is that they are not continuously conditioned. The requirements for nonresidential spaces are a little less stringent than they are for residential spaces.

Conditioned Space
The technical definition of conditioned space is that first, it must be completely enclosed by walls, roofs, floors, and/or other envelope components; and second, the space must qualify as a cooled space, a heated space, or an indirectly conditioned space. These are defined in detail below:

Cooled Space. A cooled space is one that has a cooling system with a sensible output capacity greater than 5 Btu/h·ft² (15 W/m²) of floor area.

Heated Space. A heated space is one that has a heating system with an output capacity greater than or equal to the thresholds listed in Table 5-G. For instance, if a space were located in a climate zone 3, the heating system would have to have an output capacity greater than 10 Btu/h·ft² (30 W/m²) in order for the space to be considered heated.

Indirectly Conditioned Space. An indirectly conditioned space has no heating or cooling system but is indirectly heated or cooled due to its proximity to spaces that are heated or cooled. Two criteria can be applied to determine if a space is indirectly conditioned.

- If the heat transfer rate to conditioned space is larger than the heat transfer rate to the exterior (ambient conditions), then the space is considered indirectly conditioned.
- If there is an air transfer rate between the space and conditioned space that exceeds three air changes per hour (ACH), then the space is considered indirectly conditioned. Air transfer can be provided by either natural or mechanical means.

It is really up to the designer to make a space either unconditioned or indirectly conditioned. This can be achieved by the placement of insulation or by providing (or not providing) ventilation to the space. A space on the exterior of a building can be made indirectly conditioned by placing the insulation on the exterior wall, such as with an enclosed exit stairway. This is the common approach, since usually less insulation is required. Likewise, by providing ventilation vents or fans, a space can be made indirectly conditioned.

Figure 5-N illustrates the two criteria for indirectly conditioned space. Examples 5-N and 5-O show how to make the necessary calculations when applying the two criteria.

Semiheated Space
Semiheated spaces are spaces with a small heating system. To be considered a semiheated space, the heating system must have a capacity greater than or equal to 3.4 Btu/h·ft² (10 W/m²) of floor area but less than the thresholds above so that the space is not a conditioned space (see Conditioned Space above). The general assumption is that all spaces in climates with more than 1,800 (1,000) heating degree-days at base temperature 65°F (18°C) are conditioned. Declaring a space as semiheated is an exception that must be approved by the building official. The designer must also label semiheated spaces on the construction plans that are submitted with the building permit

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application. This will enable the building official to verify that the spaces are truly semiheated and to provide documentation to the field inspector.

Unconditioned Space
Unconditioned space is neither semiheated nor conditioned. As noted in the discussion of indirectly conditioned space, it is usually the designer's choice as to whether a space is unconditioned or indirectly conditioned. The determination can be made by the placement of insulation or by providing (or not providing) ventilation. The general assumption is that all spaces in climate zones 3 through 8 are conditioned. Unconditioned space must be approved by the building official and labeled on the construction plans. This determination is based on the likely use of the space, regardless of whether mechanical equipment is included with the building permit application.

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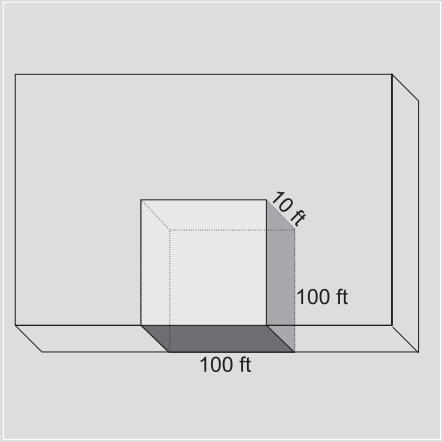
Example 5-N—Indirectly Conditioned Space, Application of Heat Transfer Criteria

Q

The following figure shows an example of a 100 ft x 100 ft x 10 ft space that is adjacent to conditioned space, but does not have a heating or cooling system. According to the heat transfer criteria, does the space qualify as indirectly conditioned? The walls that separate the space from the U-shaped conditioned space are uninsulated steel-framed walls. The exterior wall of the space is steel-framed (2x6) with R-19 insulation. The floor is an uninsulated concrete slab. The roof has metal framing at 48 in. o. c., an attic, and R-30 insulation.



A

The heat transfer criteria states that the space is considered indirectly conditioned if the rate of heat transfer between the space and conditioned space is greater than the heat transfer rate to the exterior (ambient conditions). The heat transfer rate between the space and the outdoors includes the roof, exterior wall and slab. The heat transfer rate to the exterior is 592 Btu/h·F while the heat transfer rate to adjacent conditioned space is 1,056 Btu/h·F. The space is therefore considered indirectly conditioned since the heat transfer rate to conditioned space is greater than it is to the exterior.

Heat transfer rate to the exterior:

Component	Area/ Length	U-factor/ F-factor	Heat Transfer Rate	Data Source
Roof	10,000 ft²	0.041	410	Table A2.5
Exterior Wall	1,000 ft²	0.109	109	Table A3.3
Slab length	100 ft	0.73	73	Table A6.3
Overall heat transfer rate			*592*	

Heat transfer rate between the space and the adjacent conditioned space:

Component	Area/ Length	U-factor/ F-factor	Heat Transfer Rate	Data Source
Exterior Wall	3,000 ft²	0.352	1056	Table A3.3

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Exterior Envelope
Exterior envelope components separate conditioned space from outdoor conditions, including ventilated crawl spaces and attics. Exterior envelope components enclose either nonresidential or residential spaces. For more information, see Scope and Figure 5-C in the General Information section of this chapter. The requirements that apply to exterior envelope components are those for either nonresidential or residential space categories.

Semi-Exterior Envelope
Semi-exterior envelope components separate conditioned space from unconditioned space or from semiheated space. Semi-exterior envelope components also separate semiheated space from exterior (outdoor) conditions or from unconditioned space. For more information, see Scope and Figure 5-C in the General Information section of this chapter. The requirements for semiheated space categories apply to semi-exterior envelope components.

Area-Weighted Averages
When using the Standard, it is often necessary to perform area-weighted averaging. Building designs are often complex and include many different types of roof, wall and floor construction assemblies. Also, more than one type of window or overhang will often exist in a building. In these cases, it is necessary to calculate an area-weighted average. Area-weighted averages may only be performed, however, within a single class of construction.

For instance, if a building has a number of different types of roof constructions, but all of the same class, you may need to calculate the area-weighted average in order to determine compliance. If all of the constructions independently meet the requirement, then the area-weighted average would also meet the requirement and there would be no need to perform the calculation. However, if one or more constructions fail to meet the requirement, the building may still comply with the Standard if the area-weighted average of all the constructions meet the criteria.

Area-weighted averaging can be done with U-factors, C-factors, F-factors, solar heat gain coefficients (SHGC) and overhang projection factors (PF). However, you may not average R-values. The area-weighted average is like a simple average, except that larger surfaces are weighted more heavily than smaller surfaces. To illustrate the difference between simple averaging and area-weighted averaging, suppose that a building has two roof constructions, both of the same class. The first construction represents an area of 9,000 ft² and has a U-factor of 0.030. The second construction represents an area of 1,000 ft² and a U-factor of 0.100. A simple average of 0.065 is calculated as shown here:

$$\text{Simple Average} = \frac{0.030 + 0.100}{2} = 0.065$$

Since the higher U-factor represents only 10% of the roof area, the simple average is inaccurate. The true area-weighted average is 0.037, almost half the simple average. The area-weighted average is calculated by multiplying each U-factor by its area, adding these products, and dividing the sum by the total area. The area-weighted average calculation is shown here:

$$\text{Area - Weighted Average} = \frac{9000 \times 0.030 + 1000 \times 0.100}{10000} = 0.037$$

Fenestration

The term "fenestration" refers to the light-transmitting areas of a wall or roof, mainly

Example 5-O—Indirectly Conditioned Space, Application of Air Transfer Criteria

Q

The 100 ft x 100 ft x 10 ft space described in the previous example has a fan that draws 6,000 ft³/min (cfm) of air from the adjacent conditioned space and exhausts it to the exterior. Using the air transfer rate criteria, does the space qualify as indirectly conditioned?

A

According to the air transfer criteria, if the space's air transfer rate is greater than three air changes per hour (ACH), then the space is considered to be indirectly conditioned. The volume of the space is 100,000 ft³. The fan transfers 6,000 ft³ per minute or 360,000 ft³ per hour. The air changes per hour (ACH) exchange rate is 360,000 ft³ divided by 100,000 ft³ or 3.6 air changes per hour. The space is therefore considered indirectly conditioned.

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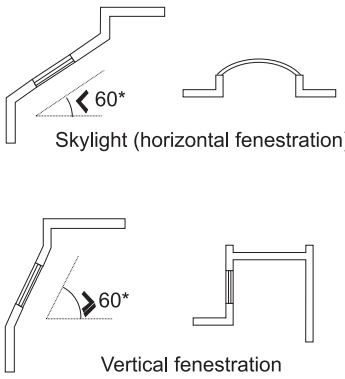

Figure 5-O—Vertical Fenestration vs. Skylights

windows and skylights, but also including glass doors, glass block walls, and translucent plastic panels. Depending on the area, heat losses and gains through fenestration can be very significant and are carefully addressed by the Standard.

Controlling solar gains through fenestration and maximizing daylighting can significantly affect energy use in buildings. Solar gains through windows add to cooling loads in the summer and during other times when the building is air-conditioned. On cold days, solar gains can also offset heating loads, although this is generally not a significant benefit in commercial buildings because high internal heat gains typically reduce the hours heating is needed when the building is occupied. The more significant benefit of sunlight is daylighting. Light is solar radiation in the visible spectrum, with a wavelength between about 380 and 770 nanometers. With the right type of electric lighting system and controls, daylight can be a significant benefit. The ideal fenestration would allow light to enter the building but block solar radiation outside the visible spectrum (in the ultraviolet and near infrared part of the solar spectrum). Residential buildings, on the other hand, can benefit from passive solar gains, depending on the climate.

The Prescriptive Building Envelope Option limits the window-wall ratio to a maximum of 40% and the skylight-roof ratio to a maximum of 5%. The prescriptive requirements also specify a maximum U-factor and a maximum SHGC. These criteria depend on either the window-wall ratio or the skylight-roof ratio.

Window-Wall Ratio

The window-wall ratio is the ratio of vertical fenestration area to gross exterior wall area. The fenestration area is the rough opening, i.e., it includes the frame, sash, and other nonglazed window components. The gross exterior wall is measured horizontally from the exterior surface; it is measured vertically from the top of the floor to the bottom of the roof. The gross exterior wall area includes below-grade as well as above-grade walls. It is necessary to calculate the window-wall ratio with all compliance options, since this information is needed with the prescriptive option, the trade-off option, and the energy cost budget method.

Sloping glazing falls in the vertical category if it has a slope equal to or more than 60 degrees from the horizontal. If it slopes less than 60 degrees from the horizontal, the fenestration falls in the skylight category (see Figure 5-O). This means that clerestories, roof monitors, and other such fenestration fall in the vertical category.

Skylight-Roof Ratio

Skylights are fenestration with a slope less than 60 degrees from the horizontal (see Figure 5-O). The skylight-roof ratio is the ratio of skylight area to the gross roof area. The skylight area is the rough opening and includes the frame and other components of the manufactured assembly. The gross roof area is measured to the outside surface of the roof. The roof area is measured along the surface that encloses the conditioned space. For a flat roof and flat ceiling, the roof area is the same as shown in plan view. For an attic with a pitched roof over a flat ceiling enclosing conditioned space, the roof area is again the same as shown in plan view. However, for sloped ceilings or vaulted ceilings, roofs are measured along the slope, as opposed to the projection onto a horizontal plane that would show on a floor plan.

Fenestration U-Factor

Fenestration U-factor is the rate of heat flow through one square foot of fenestration when there is a one-degree temperature difference between the air on one side and the air on the other side. The inch-pound units are Btu per hour per degree Fahrenheit or Btu/h ·°F (the metric or SI units are W/m² ·ºC). The U-factor includes consideration of the whole fenestration product. Heat loss is accounted for through the glass, edge of glass as well as the sash and frame elements. For skylights, heat loss also includes the skylight curb. The heat loss is then normalized for the area of the rough frame opening provided for the fenestration.

U-factor does not consider solar gains through the fenestration; this is addressed by the solar heat gain coefficient (SHGC) or the shading coefficient (SC). However, the fenestration U-factor be determined using methods specified in the Fenestration and Doors section of Product Information (§ 5.8.2), which references National Fenestration Rating Council (NFRC) procedures, and NFRC-100, in particular.

NFRC-100 is based on a combination of computer simulations and laboratory testing. The NFRC goal is to provide a

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consistent and accurate estimate of the U-factor of fenestration products.

Note: Test procedures for site-assembled products are contained in the 2001 version of NFRC 100, which contains additional terminology, a default specimen description for validation and the ability to determine ratings that are size-specific. The revised NFRC procedures for site-built products relate primarily to the certification of the product or system, not in how the U-factor or SHGC ratings are determined. In order to provide a uniform comparison for site-built products, the standard size for rating information is 80 in. by 80 in., with one vertical mullion and two glazed lites.

To comply with the Standard, fenestration products must have an NFRC label (or label certificate) based on a rating certification using NFRC 100, or they must qualify as skylights as determined by NFRC 100. Those fenestration products that do not qualify as skylights and do not have an NFRC rating must use the default U-factors published in Table A8.2 of Standard 90.1-2007, Appendix A. The U-factors in this table are on the high side of the range of fenestration products represented in order to encourage fenestration manufacturers to have their products rated and certified in accordance with NFRC procedures.

Many buildings have more than one type of window. In these cases, an area-weighted average U-factor may be calculated (see Area-Weighted Averages). However, a separate area-weighted U-factor must be calculated for each class of fenestration, e.g., operable windows separate from fixed windows and plastic skylights separate from glass skylights.

Solar Heat Gain Coefficient (SHGC)

The solar heat gain coefficient (SHGC) is the ratio of solar radiation that passes through fenestration to the amount of solar radiation that falls on the fenestration. Perfectly transmitting fenestration would have an SHGC of 1.0, but this is a physical impossibility, since even the most clear glass blocks some solar radiation. SHGC is also a whole product rating and accounts for the glazing material as well as the frame and sash. The SHGC is a property of the fenestration produc t and does not account for interior shading from Venetian blinds, vertical blinds, or draperies.

The Standard requires that SHGC be determined in accordance with NFRC 200 by a laboratory that has accreditation by NFRC or a similar organization. Fenestration products that have an NFRC rating report the SHGC as well as the U-factor.

For those products with NFRC ratings, those SHGC values shall be used.

If SHGC data are not available (for instance, for glazed wall systems), the designer can use the manufacturer's shading coefficient (SC) data and modify it by multiplying it by a factor of 0.86, provided that the shading coefficient is established using a spectral data file determined in accordance with NFRC 300. The adjustment accounts for the differences between SHGC and SC, including frame effects. (See the definition of shading coefficient below.) For unlabeled glazed wall systems and skylights, an alternative is to use Table A8.1B in Appendix A. For other unlabeled products, use Table A8.2. However, this table is unlikely to be very helpful since it is limited to just a few products with high values of SHGC. Thus, for advanced glazing products, the manufacturers' data is a better source.

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Shading Coefficient (SC)

The shading coefficient is a number between zero and one that indicates the amount of solar heat gain that will pass through fenestration. By definition, the shading coefficient of ⅛ in. thick, clear, double-strength window glass is 1.0. All other fenestration is rated relative to this. If a window has a shading coefficient of 0.5, it means that it will allow into the building only half the solar heat gain as the same size window with ⅛ in. clear glass. The shading coefficient of glass and other materials depends on the thickness of the material, the number of panes, any tinting that is mixed with the glass when it is manufactured, and any special coatings that are applied to the surface of the glass.

Shading coefficient is being replaced by SHGC, so its use is limited. When SHGC data are not available for glazed wall systems and skylights, the SHGC can be determined from the SC by multiplying the SC by a factor of 0.86, provided that the shading coefficient is established using a spectral data file determined in accordance with NFRC 300. This factor accounts for the differences between the two figures of merit and for the effect of a default frame.

Interior Fenestration Shading

Interior shading devices are not considered for compliance calculations in ANSI/ASHRAE/IESNA *Standard 90.1-2007*. However, interior shading was taken into account when determining the new fenestration criteria. Had interior shading not been considered, the criteria would be more stringent. The main reason that interior devices are not credited in the compliance process is that that they are usually not known at the time a building permit is issued for the building envelope. Interior shading devices are more often included in the construction for tenant improvements, which comes later in the

Example 5-P—SHGC, Office Tower with Lower-Level Retail

Q

What is the area-weighted average SHGC for a 15-story rectangular building that has two floors of retail at the ground level and 16 stories of office above?

Each retail story has 500 ft² of fenestration on the south side, 850 ft² on the east side, and none on the other two sides. Each office floor has 400 ft² on both the north and south sides and 480 ft² on the east and west sides. All the fenestration is double-glazed with a low-e coating. The clear low-e on the retail stories has an SHGC of 0.71, while the SHGC is 0.48 for the tinted low-e on the office floors.

A

For the prescriptive option, calculate an area-weighted average SHGC for all fenestration.

$SHGC_{overall}$ = {[(500 + 850) × 0.71 × 2 stories]
+ [(400 + 480 + 400 + 480) × 0.48 × 16 stories]}/{[(500 + 850) × 2 stories]
+ [(400 + 480 + 400 + 480) × 16 stories]} = (1,917 + 13,517)/(2,700 + 28,160) = 0.50

Note: When using EnvStd, there is no need to calculate the area-weighted average SHGC. Just enter each window separately into the program.

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building process. However, even when installed, their use is unpredictable and they can be readily changed or replaced by users unaware of the energy implications. Consequently, their long-term effectiveness cannot be counted upon. The benefit of interior shading devices depends on the glazing material. A white roller shade, for instance, is more effective with clear glass than with low transmission reflective glass. This is because its effectiveness depends on the ability of the shading device to reflect solar radiation back out the window and this ability is increased with high transmission glass.

Exterior Fenestration Shading
The most effective way to control solar heat gains through windows is to intercept the sun before it strikes the window. Exterior shading devices can be an effective means of achieving this. Exterior shading devices include horizontal or vertical fixed-position louvers, moveable louvers, and sunscreens. Sunscreens are often decorative in nature and range in style from large pattern aluminum or metal screens to miniature louvers that enable less obstructed views. Exterior shading devices can be considered in complying with the Standard if they are permanent projections that will last as long as the building itself.

Visible Light Transmittance (VLT)
Visible light transmittance (VLT) is the fraction of solar radiation in the visible spectrum that passes through fenestration. VLT is important for daylighted buildings. It is also important in order to enjoy views from windows. The quality of the view is directly proportional to the VLT. The higher the VLT, the better the view.

There is a strong relationship between the visible light transmittance and the solar heat gain coefficient. The lower the solar heat gain coefficient, generally the lower the visible light transmittance. Some glazing products, however, have a VLT higher than other products with the same solar heat gain coefficient. For instance, bronze, gray, and green tinted glass all have about the same shading coefficient for a given glass thickness, but green glass has a significantly higher visible light transmittance. Likewise, some coatings applied to the surface of glazing reduce the shading coefficient more than they do the VLT. For these reasons, manufacturer's literature should be carefully consulted in the selection of glazing products. For good daylighting without excessive solar gain, look for a product whose VLT is at least 1.2 times the SHGC.

VLT is not considered with the Prescriptive Building Envelope Option but is considered with the Building Envelope Trade-Off Option. When using the EnvStd computer program, which incorporates the trade-off option, it is necessary to know the VLT for each window and skylight. Visible light transmittance is to be determined in accordance with NFRC 200. For unlabeled glazed wall systems and skylights, default values are provided in Table A8.1B of Appendix A. For other unlabeled products, use Table A8.2.

Profile Angle
The profile angle is the elevation of the sun in the direction of a normal vector projecting from the surface of a window. It is necessary to determine the profile angle in order to determine if a louvered overhang qualifies for credit under either the prescriptive requirements or the building envelope trade-off option (EnvStd).

The profile angle depends on the orientation of the window as well as the altitude and azimuth of the sun.

Projection Factor (PF)
External shading by overhangs is credited toward reducing solar gain with both the Prescriptive Building Envelope Option and the Building Envelope Trade-off Option. The concept of projection factor is used to characterize the performance of overhangs. Projection factor is the ratio of the projection (P) of the overhang from the glazing surface to the height (H) distance from the windowsill to the bottom of the overhang (see Figure 5-L).

Neither the prescriptive method nor the Building Envelope Trade-Off Option gives benefits to overhangs with projection factors greater than 1.00. An overhang with a projection factor of 1.00 has a projection equal to the distance from the windowsill to the bottom of the overhang. In order for glazing area to qualify as shaded by an overhang, the overhang must extend beyond the right and left edges of the window a distance at least as great as the overhang projection.

When different overhang conditions exist, it is necessary to calculate an area-weighted average if you are using the prescriptive option. The weighting is based on the window area that is shaded. For the EnvStd program, the projection factor of each window can be separately entered.

When using EnvStd, the designer should be aware that the projection factor reduction in radiation applies to both the shading coefficient and to the visible light transmittance. This means that although overhangs provide beneficial reductions in solar gain, they also reduce useful daylight.

Vertical Fenestration Classes
There are four classes of vertical fenestration which are based on frame type: nonmetal frames, metal frames use for curtain walls and storefronts, metal frames used for entrance doors and other metal frames. The Standard has separate

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criteria for these classes of vertical fenestration. For determining compliance, there are some additional classifications, however. These include:

- *Labeled Fenestration*: This subclass includes all fenestration products that have an NFRC rating. Such products are required to be labeled. Information on the label includes the U-factor, SHGC, VLT, and other data. For this subclass, fenestration performance data used for compliance with the Standard must be taken from the label or the NFRC rating.
- *Other Unlabeled Vertical Fenestration* (§ A8.2): This subclass includes all fenestration products that do not have NFRC ratings. Compliance data for this subclass must be taken from Table A8.2 of Appendix A.

Skylight Classes

There are three classes of skylights: glass skylight with curb, plastic skylight with curb, and skylights with no curb. Skylights with a curb (either glass or plastic) are generally pre-manufactured while skylights without a curb are usually the roof of an atrium or other special skylight. The Standard has separate U-factor and SHGC criteria for these three classes of skylights. For demonstrating compliance, there are additional classifications similar to vertical fenestration:

- *Labeled Fenestration*: All skylights with NFRC ratings are required to be labeled with those values.
- *Unlabeled Skylights* (§ A8.1): For unlabeled skylights, U-factors shall be taken from Table A8.1A of Appendix A; overall product SHGC values may be taken from Table A8.1B of Appendix A or manufacturers' SC or SHGC data for the center of the glass may be used provided that the data are established using a spectral data file determined in accordance with NFRC 300. If manufacturers' SC data are used, convert to SHGC by multiplying the SC by 0.86.

Opaque Surfaces

This portion of the Reference section addresses opaque surfaces and the performance characteristics of opaque surfaces that are relevant to the Standard. The concepts of U-factor, R-value, and heat capacity (HC) are reviewed and defined. The different envelope component types are reviewed along with the classes of construction for each type. For cases where the default U-factors in the Appendix A tables do not adequately represent an assembly, the Standard has requirements for how U-factors can be calculated for different classes of construction. These calculation methods are reviewed and examples are provided for some of the classes. This section is intended for use with both the Prescriptive Building Envelope Option and the Building Envelope Trade-Off Option.

U-Factor

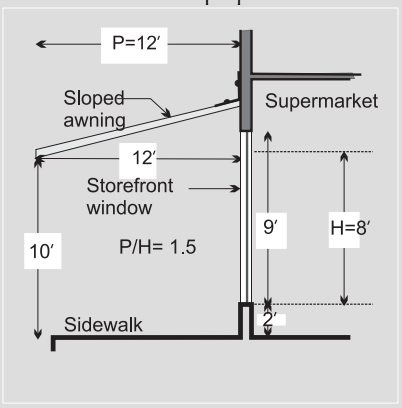
When it is colder on one side of an envelope element, such as a wall, roof, floor, or window, heat will conduct from the warmer side to the cooler side. Heat conduction is driven by temperature differences and represents a major component of heating and cooling loads in buildings. The building envelope requirements address heat conduction by specifying minimum R-values (thermal resistance to heat flow) for insulation and/or maximum U-factors (the rate of steady-state heat flow) for building envelope construction assemblies.

The U-factor is the rate of steady-state heat flow. In inch-pound units, it is the amount of heat in Btu (British thermal units) that flows each hour through one square foot when there is a one-degree temperature difference between the inside

Example 5-Q—Projection Factor, Supermarket with Awning

Q

What is the projection factor for a single-story supermarket with a sloped metal awning that extends 12 ft out from the surface of the glass and at its lowest point is 10 ft above the sidewalk? The storefront window starts at 2 ft above the floor and has a height of 9 ft. Assume that the sidewalk and the floor are at the same level. The fenestration is only on the west side of the building facing the parking lot; all other facades are opaque.



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The projection factor is the ratio of the horizontal projection of the overhang to the distance from the windowsill to the bottom of the overhang. The horizontal projection is 12 ft and the vertical distance from the windowsill to the bottom of the overhang is 8 ft. The projection factor is, therefore, 12 ft divided by 8 ft or 1.5. The overhang multiplier is 0.44 (see Table 5.5.4.4.1). The SHGC of the supermarket fenestration is multiplied times 0.44 and this product is compared to the criteria SHGC. Note that Table 5.5.4.4.1 does not offer additional shading credit for projection factors greater than one.

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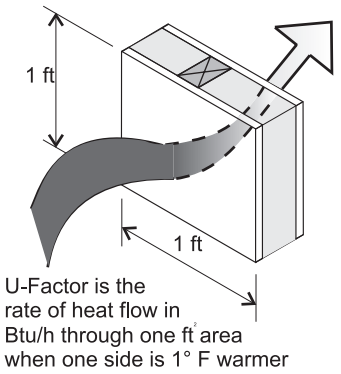

Figure 5-P—The U-Factor Concept

air and outdoor air. The heat flow can be in either direction, as heat will flow from the warmer side to the cooler side. With some constructions, the rate of heat flow may vary with the direction of flow. Steady-state heat flow assumes that temperatures on both sides of the building envelope element (while different) are held constant for a sufficient period so that heat flow on both sides of the assembly is steady. The steady-state heat flow method is a simplification, because in the real world, temperatures change constantly. However, it can predict average heat flow rates over time and is used by the Standard to limit conductive heat losses and gains. Because they are easy to understand and use, the terms for steady-state heat flow (R-values and U-factors) are part of the basic vocabulary of building energy performance.

Each layer of a building assembly, such as the sheathing and the insulation, has its own conductance, or rate of heat transfer. The conductance for an individual layer is similar to the U-factor, and it has the same units. When there are multiple elements in a layer, such as wood studs and cavity insulation, the calculations must adjust for the different heat flow rates. Especially with metal framing, these thermal bridges have a significant impact on the performance of the overall assembly, sometimes reducing the insulation effectiveness to less than half. The U-factor accounts for the conductance of every element of the construction assembly, including the air film conductances on the interior and exterior surfaces. The air film conductances quantify the rate at which heat is transferred between the surface of the construction assembly and the surrounding environment. This conductance depends on the orientation and roughness of the surface and the wind speed across the surface.

For light frame walls, U-factors provide an adequate description of heat transfer. For heavy concrete and masonry walls, however, this is only true under constant temperature conditions. The dynamic heat storage properties of the concrete and masonry alter the thermal behavior of the wall, and the U-factor becomes less accurate as a predictor of heat flow.

R-Value

R-values are also used to describe steady-state heat flow but in a slightly different way. The R-value is the thermal resistance to heat flow. A larger R-value has greater thermal resistance, or more insulating ability, than a smaller R-value.

R-value is widely recognized in the building industry and is used to describe insulation effectiveness. Consequently, the prescriptive criteria tables contain a compliance option that is based on the R-value of the insulation alone. The insulation R-value does not describe the overall performance of the complete assembly, however. It only describes the thermal resistance of the insulation material. The performance of the entire wall assembly can be significantly lower when metal framing penetrates the insulation.

Most construction assemblies include more than one material in the same layer. For example, a wood stud wall includes cavity areas where the insulation is located and other areas where there are solid wood framing members. The wood areas have a lower R-value and conduct heat more readily than the insulated areas. It is incorrect to neglect framing members when calculating the U-factor for the wall, roof, or floor assembly. The correct U-factor includes the insulation portion of the wall as well as the solid (or framed) portion of the wall.

Appendix A contains tables of U-factors for a range of insulation options for many construction assemblies. These have been carefully calculated using ASHRAE procedures and are to be used for compliance with the U-factor options. This simplifies compliance for the designer and the building official by eliminating the need to perform and review U-factor calculations. However, there may be some cases where an assembly is not adequately represented in Appendix A. Where allowed by § A1.2, the Standard requires that the U-factor of each envelope assembly be calculated taking into account framing and other thermal bridges within the construction assembly. The method to be used depends on the class of construction and other factors.

Heat Capacity (HC)

Heat capacity (HC) is the amount of heat that must be added to one square unit of surface area in order to elevate the temperature of the construction uniformly by one degree Fahrenheit. The inch-pound units are British thermal units per square foot per degree Fahrenheit (Btu/ft^2·°F). The metric or SI units are kilojoules per

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square meter per degree Celsius (kJ/m² ºC).

HC is used in the Standard to quantify the amount of thermal mass in exterior walls and floors. With the prescriptive option, the HC must be known in order to determine if a wall is a mass wall or if a floor is a mass floor. It is used the same way in the Building Envelope Trade-Off Option, but in addition, HC is a significant factor in determining the envelope performance factor. HC may also be used with the energy cost budget method, although in this case, the various construction layers are usually modeled separately.

Heat capacity for mass walls is to be taken from Table A3.1B or A3.1C. The heat capacities in Table A3.1B, but not the U-factors, are also appropriate for solid concrete mass floors. Where these are not adequate, HC is calculated as follows:

$$HC = \sum_{i=1}^{n} Density_i \times Specific\ Heat_i \times Thickness_i$$

Essentially, HC is the sum of the heat capacity of each individual layer in the wall. The heat capacity of each layer is the density of the material multiplied by the thickness times the specific heat (all in consistent units). With the equation above, the term "*i*" is an index of each layer in the construction and "n" is the total number of layers in the construction. Layers that have insignificant thermal mass (such as the air films) can be ignored. When layers have more than one material, for instance a framed wall with insulation in the cavity, each separate material is weighted in proportion to its projected area.

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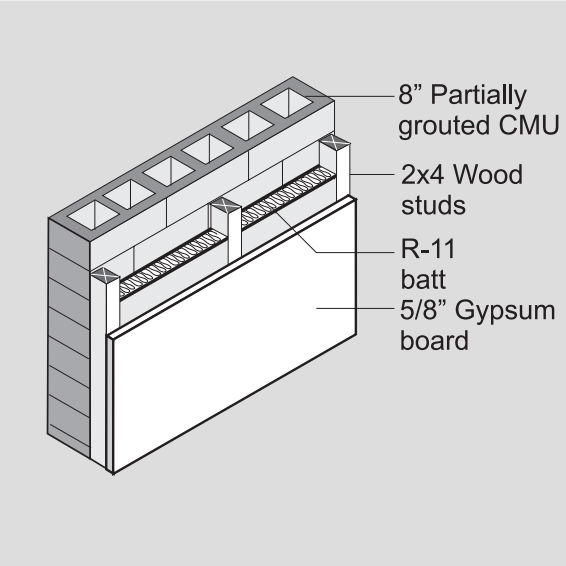
Example 5-R—HC Calculation

Q

What is the heat capacity (HC) for the wall construction depicted below? The exterior wall consists of 4 in. of face brick, a 1.5 in. air gap, 8 in. partially grouted CMU with a density of 105 lb/ft³ (cells uninsulated). The interior has R-11 batt insulation between 2x4 wood studs spaced at 16 in. o.c. The interior finish is ⅝ in. gypsum board.



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The HC is the sum of the density times the specific heat times the thickness for each layer of the wall. The calculation can be structured in tabular form as shown below.

Item	Weight (lb/ft^3)	Fraction of Wall	Specific Heat (Btu/lb·°F)	HC (Btu/ft^2·°F)	Data Source
4 in. Face Brick	47.00	1.00	0.20	9.40	*ASHRAE Handbook*
Air Gap	0	1.00	0	0	
8 in. Partially Grouted CMU (105 lb/ft³)	47.00	1.00	0.20	10.20	*Standard 90.1-2007* (Table A3.1C)
2x4 Wood Studs	9.30	0.22	0.33	0.46	*ASHRAE Handbook*
R-11 Batt	0.25	0.78	0.30	0.06	*ASHRAE Handbook*
⅝ in. Gypsum Board	2.60	1.00	0.26	0.68	*ASHRAE Handbook*
TOTAL				20.80	

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Solar Reflectance

Solar reflectance is the portion of the sun's radiation that is reflected by a surface. A perfect reflector has a reflectance of 1.0, and a perfect absorber has a reflectance of zero. These are both physical impossibilities. No surface (not even mirrors) reflects all radiation and no surface (not even flat black paint) absorbs all the heat from the sun. Radiation that is not reflected is absorbed. The sum of the fraction of radiation that is reflected, transmitted and absorbed must equal one.

In hot climates, it is desirable that surfaces—especially roof surfaces—have a high solar reflectance. This means that they must have a light color. When a surface has a high solar reflectance and a high emittance, it qualifies for special consideration or credits. It order to qualify for the credit, the solar reflectance of the surface must be greater than 0.70 when laboratory tested in accordance with the ASTM E903 test procedure.

Emittance

Emittance is the ability of a surface to radiate heat. This is in contrast to reflectance and absorptance, which describe a surface's ability to receive radiation. Like reflectance and absorptance, the emittance is a property of the surface, not the material. For instance,

Table 5-H—Required Procedures for Determining Alternative U-, C-, and F-Factors for Opaque Assemblies

	Acceptable Calculation Methods					
Construction Classes	*Testing*	*Series Calculation Method*	*Parallel Path Calculation Method*	*Isothermal Planes*	*Modified Zone Method*	*Two-dimensiona Calculation Meth*
Roofs						
Insulation Entirely above Deck	✓	✓				✓
Metal Building	✓					✓
Attic (wood joists)	✓		✓			✓
Attic (steel joists)	✓			✓ (1)	✓	✓
Attic (concrete joists)	✓	✓ (2)		✓ (3)		✓
Other	✓					✓
Walls, Above-Grade						
Mass	✓			✓		✓
Metal Building	✓					✓
Steel-Framed	✓			✓ (1)	✓	✓
Wood-Framed	✓		✓			✓
Other	✓					✓
Wall, Below-Grade						
Mass	✓			✓		✓
Other	✓					✓
Floors						
Mass	✓	✓ (2)		✓ (3)		✓
Steel-Joist	✓			✓ (1)	✓	✓
Wood-Framed	✓		✓	✓		✓
Other	✓					✓
Slab-On-Grade Floors						
Unheated						✓
Heated						✓

Notes:

1. Must use the insulation/framing layer adjustment factors from Tables A9.2A or A9.2B of Appendix A.
2. Use only if concrete is solid and uniform.
3. Use if the concrete has hollow sections.

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polished aluminum and brushed aluminum have very different values for reflectance, absorptance, and emittance.

When the building needs cooling, it is desirable for exterior surfaces, especially roofs, to have a high emittance. This allows heat absorbed by the roof to escape through radiation. At night, this is especially important since the temperature of the night sky is low and a great deal of heat can escape by radiation. The Standard offers a credit in warm climates when the thermal emittance is greater than 0.75 when laboratory tested according to the ASTM E408 test procedure.

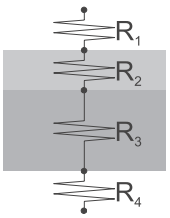
Acceptable Calculation Methods

In most cases, the default tables in Appendix A are to be used to determine U-factors, F-factors, C-factors, and other figures of merits. § A1.2 contains criteria for a building official to determine if a proposed construction assembly is adequately represented. This determination is related to whether the base assembly is the same and whether the building materials are significantly different from those described in § A2 to A8. If this is the case, it is necessary to calculate the U-factor. For this situation, § A9 of the Standard specifies acceptable calculation methods. These are related to the classes of opaque construction that are identified in the Standard, although in some cases a class is expanded. Table 5-H shows the calculation methods that can be used with each class of construction. U-factors for opaque doors shall be determined in accordance with § 5.4.3.6 or § A7 only.

Testing

Laboratory tests are the most accurate way to determine the U-factor of a construction assembly and are acceptable for all types of construction except slabs-on-grade. In these tests, an 8 ft by 8 ft sample of the construction assembly is placed in a test unit. For steady-state measurements, the temperatures on either side of the wall are held constant until temperatures within the construction have stabilized; then the rate of heat flow is measured. Heat flow is typically measured by metering the heat energy required to maintain temperature on the warm side of the assembly. The biggest advantage of laboratory testing is that it produces equally good results for just about any type of construction assembly. The major disadvantage is that it is costly and time consuming. There are a large variety of possible construction assemblies, and it is impractical to test them all. For this reason, it is usually more cost-effective to use calculation methods if allowed. Laboratory measurements must use one of the following test procedures:

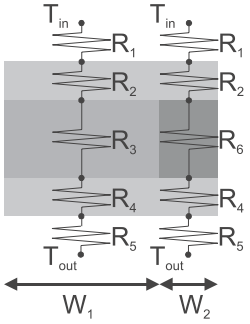
- Guarded Hot Plate (ASTM C-177)
- Heat Flow Meter (ASTM C-518)
- Hot Box Apparatus (ASTM C-1363)



$$U = \frac{1}{R_1 + R_2 + R_3 + R_4} \qquad (5\text{-B})$$

Series Calculation Method

The series calculation method is the easiest way of calculating U-factor. However, its use is limited to constructions that have no framing and are made of homogenous materials. In reality, few construction assemblies meet these strict requirements. With the series calculation method, the thermal resistance of each layer in the construction assembly is determined. Tables A9.4B through A9.4E of Appendix A have data on the thermal resistance of materials that can be used in the calculations. Test data may be used for materials not listed in Appendix A. The total thermal resistance is the sum of individual resistances, and the U-factor is the reciprocal of the total resistance. In Equation 5-A, R_1 and R_4 are the air film resistances, while R_2 and R_3 are the resistances of the two materials in the construction.



$$U_1 = \frac{1}{R_1 + R_2 + R_3 + R_4 + R_5} \qquad (5\text{-C})$$

$$U_2 = \frac{1}{R_1 + R_2 + R_6 + R_4 + R_5}$$

$$U = U_1 \cdot W_1 + U_2 \cdot W_2$$

Parallel Path Calculation Method

The parallel path calculation method is a simple extension of the series calculation method that can be used for wood-framed assemblies. Essentially, a series calculation method is performed twice, once for the cavity portion of the surface (roof, wall or floor) and once for the framing portion of the wall. In some cases, it may be necessary to divide a surface into more than two parts (for instance, see Example 5-V). The U-factor is calculated for each sub-area (U_1 and U_2 in the equations) and

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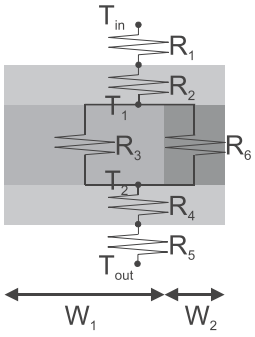
weighted according to surface area. The W_1 and W_2 terms in the equations are weightings for each sub-area. The sum of all weightings should equal one. With the parallel path method the temperature of the outdoor air (T_{Out}) and the inside air (T_{In}) are the same for each path; however, the surface temperatures may be different through each path. To put it another way, the outside wall temperature will be warmer near framing members on a cold day. These temperature differences can be detected by infrared photography, which is a useful tool for finding thermal bridges in construction facilities.



$$U = \frac{1}{R_1 + R_2 + \left[\frac{1}{W_1\left(\frac{1}{R_3}\right) + W_1\left(\frac{1}{R_6}\right)}\right] + R_4 + R_5} \qquad \text{(5-D)}$$

$$U = \frac{1}{R_1 + R_2 + R_{Effective} + R_4 + R_5}$$

Isothermal Planes Method

The isothermal planes calculation method uses principles similar to the series and parallel path calculation methods, except that the temperature through one or more planes in the construction assembly is assumed constant (*iso* is the Greek word for equal). The isothermal planes method is appropriate for walls made of concrete or concrete masonry units (CMU) where high material conductance causes equal (or near equal) temperature across one or more planes in the construction assembly. In the network diagram above, the temperature across the R_3 and R_6 thermal resistances is assumed equal. A parallel path calculation method can be performed to determine the effective R-value through the R_3 and R_6 (see the portion of the Equation 5-D).

In the Equation 5-D, the effective R-value across resistances R_3 and R_6 is calculated using the parallel path method. However, for many construction types such as steel-framed walls, the parallel path method is inappropriate and may not be used. For steel-framed constructions, the overall U-factor can be determined through laboratory tests and then the effective R-value can be calculated as shown below. This procedure is the basis of the effective R-values published in Tables A9.2A and A9.2B of Appendix A. Using these effective R-values is really a variation on the isothermal planes method covered in Equation 5-D.

$$U = \frac{1}{R_1 + R_2 + R_{Effective} + R_4 + R_5} \qquad \text{(5-E)}$$

$$R_1 + R_2 + R_{Effective} + R_4 + R_5 = \frac{1}{U}$$

$$R_{Effective} = \frac{1}{U} - \left(R_1 + R_2 + R_4 + R_5\right)$$

Modified Zone Method

The modified zone method can be used with roof, floor and wall constructions that have metal framing. The method may be used when roofs, walls or floors are not adequately addressed in Tables A9.2A or A9.2B. The method is documented in the 1997 *ASHRAE Handbook—Fundamentals.* It involves dividing the construction assembly into zones. Heat flow in the zone near the metal framing is directed toward the framing and the thermal resistance is smaller.

Two-Dimensional Heat Flow

Two-dimensional heat flow analysis (illustrated in Figure 5-R) may be used to accurately predict the U-factor of a complex construction assembly. While the series and parallel path calculation methods assume that heat flows in a straight line from the warm side of the construction to the cooler side, with two-dimensional models, heat can also flow laterally in the construction, following the path of least resistance. Calculating two-dimensional heat flow involves advanced mathematics and is best performed with a computer.

To use the method, you divide the construction into a large number of small pieces and define the thermal resistance between each piece. The result is analyzed with electric circuit theory. The network consists of a rectangular array of nodes connected by resistances. As in the real material, the energy flow will take the path of least resistance. The computer can perform the complicated calculations necessary to solve the network, yielding the U-factor for the unit at steady state. It can also solve the network for dynamic energy conditions.

Short of performing laboratory tests, this is the most accurate method available for determining the U-factors of concrete and masonry walls. Three-dimensional heat flow analysis follows the same process, except that the thermal grid extends in three dimensions, rather than just two.

Roof Classes (§ A2)

The Standard establishes three classes of roof constructions: roofs with insulation located entirely above the deck; metal building roofs; and all other roofs. This section describes the differences between

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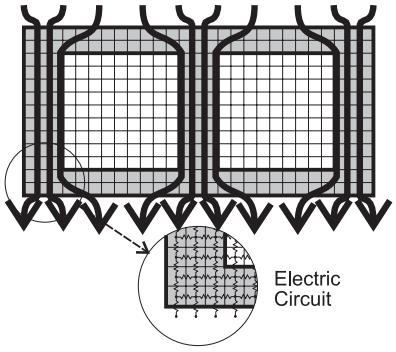

Figure 5-R—Two-Dimensional Heat Flow Analysis

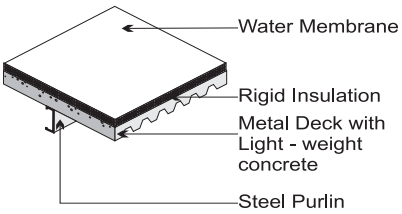

Figure 5-Q—Roof, Insulation Entirely Above Deck

these classes of construction and reviews methods that can be used to determine the U-factor of different types of constructions. Information in this section is applicable to both the Prescriptive Building Envelope Option and the Building Envelope Trade-Off Option.

Roofs with Insulation Entirely above Deck (§ A2.2)

The defining characteristic of this class of construction (shown in Figure 5-Q) is that all insulation is located above the structural deck. Roof constructions that have no insulation cannot belong to this class; neither can constructions that have insulation both above and below the structural deck. The insulation is usually a rigid foam or high-density mineral fiber. U-factors for this class are to be taken directly from Table A2.2 of the Standard's Appendix A. The U-factors in Table A2.2 include the thermal resistance of an exterior and interior air film, but nothing else. The insulation is supported directly on a metal deck that has no significant resistance to heat. As described in § A1.2, if your construction assembly has materials other than the insulation that contribute to the thermal resistance, you can use the series calculation method to calculate your own U-factor (see Reference section). Calculations shall only be made when the additional non-insulation materials have a thermal resistance greater than R-2 (R-0.35).

Metal Building Roofs (§ A2.3)

Metal building roofs are a component of prefabricated buildings. A metal structural deck is supported over metal structural supports and does double duty as a waterproof membrane. Insulation is installed on the underside of the metal deck/membrane. Usually batt insulation is draped over the structural supports. The metal panels are then attached, compressing the insulation at the supports. Rigid, continuous insulation can also be installed between the supports and the deck (see Figure 5-S).

Heat transfer in metal buildings is complex. The construction consists of highly conductive metal and compressed insulation at the supports. For these reasons, you would need to use a two-dimensional heat transfer model or laboratory testing in order to determine the U-factor. However, for most construction projects, the cost of testing or of doing two-dimensional heat transfer analysis is prohibitive. In the future, data generated from testing or two-dimensional analysis might be available by industry groups to supplement data in Appendix A, but for now, Table A2.3 is the only acceptable U-factor data available for metal building roofs. This table gives data for a number of insulation configurations, including one and two layers of batt insulation installed beneath the deck. These options can be combined with different thicknesses of continuous insulation.

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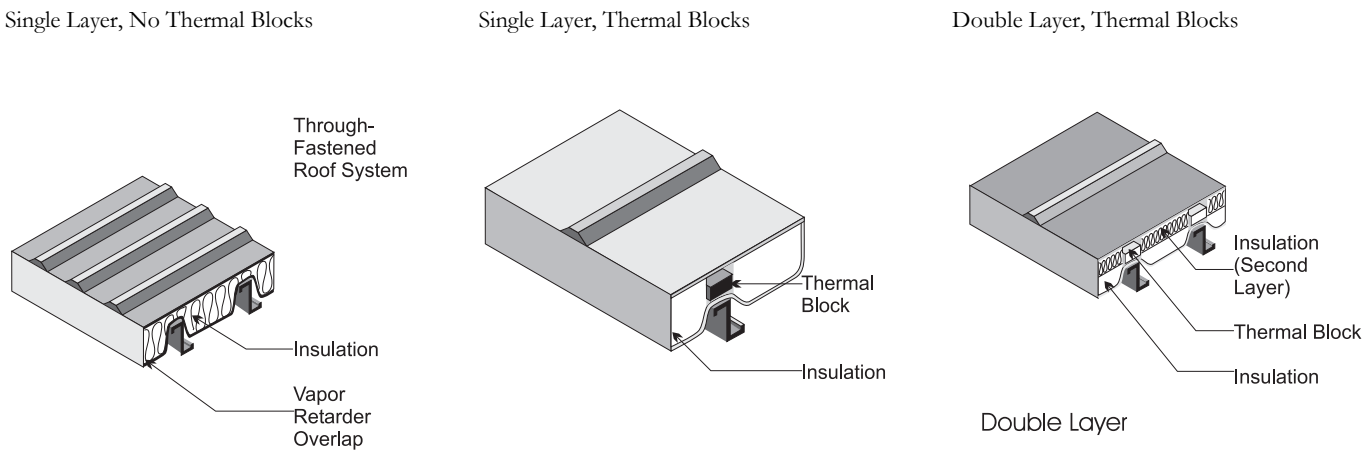

Figure 5-S—Roof, Metal Building

Attics and Other Roofs (§ A2.4 and A2.5) This class of roof construction includes all roofs that are not metal building roofs or do not have all the insulation installed above the structural deck. Roofs that have no insulation fall into this category. This class covers many different kinds of construction, since it is a "catch all" for all roofs not in one of the other classes. Any roof that has insulation installed beneath the structural deck belongs to this class. Figure 5-T shows examples of roof constructions that belong to this class. They include attic roofs with either metal or wood framing members and single-rafter roofs where the interior finish is installed on the bottom of the rafter and the structural deck above. Concrete roofs or metal deck roofs can also belong to this class, depending on the position of the insulation.

Appendix A has a number of data tables that can be used for this class of roofs. Table A2.4 has data for attic roofs with wood joists. These are common for low-rise residential construction but are used for light commercial buildings as well. Data are provided in the table for both standard trusses and advanced framing. The difference is that advanced framing has a raised heel or other framing technique that permits the full depth of insulation to extend to the building walls. With a standard truss, the insulation must be tapered or compressed near the eaves since the clearance is reduced. Table A2.3 also provides data for single-rafter wood roofs. When using the single-rafter data, the specified insulation may not be compressed. U-factors in Table A2.3 account for a layer of 5/8 in. gypsum board (R-0.56), an inside air film (R-0.61), and an exterior air film (R-0.46). The exterior air film resistance is a little higher than normal because the air is assumed to be a semi-exterior space, i.e., inside an attic. If allowed by § A1.2, you can also calculate the U-factor for wood-framed attics and single-rafter roofs using the parallel path calculation method or laboratory testing.

Use the U-factor data in Table A2.5 for any attic roof with steel joists. These U-factors are based on steel joists spaced at 48 inches o. c. or greater. Data in the table include the thermal resistance of an inside air film (R-0.61) and an exterior air film (R-0.17). Batt insulation is assumed to be installed on the underside of a metal deck. The metal deck is assumed to have no significant thermal resistance. The steel joists interrupt the continuity of the insulation. Steel joists are more conductive than wood and acceptable procedures for calculating U-factors are more complex. Acceptable calculation methods include laboratory testing, the modified zone method, and the isothermal planes method in combination with the effective R-values from Table A9.2A of Appendix A.

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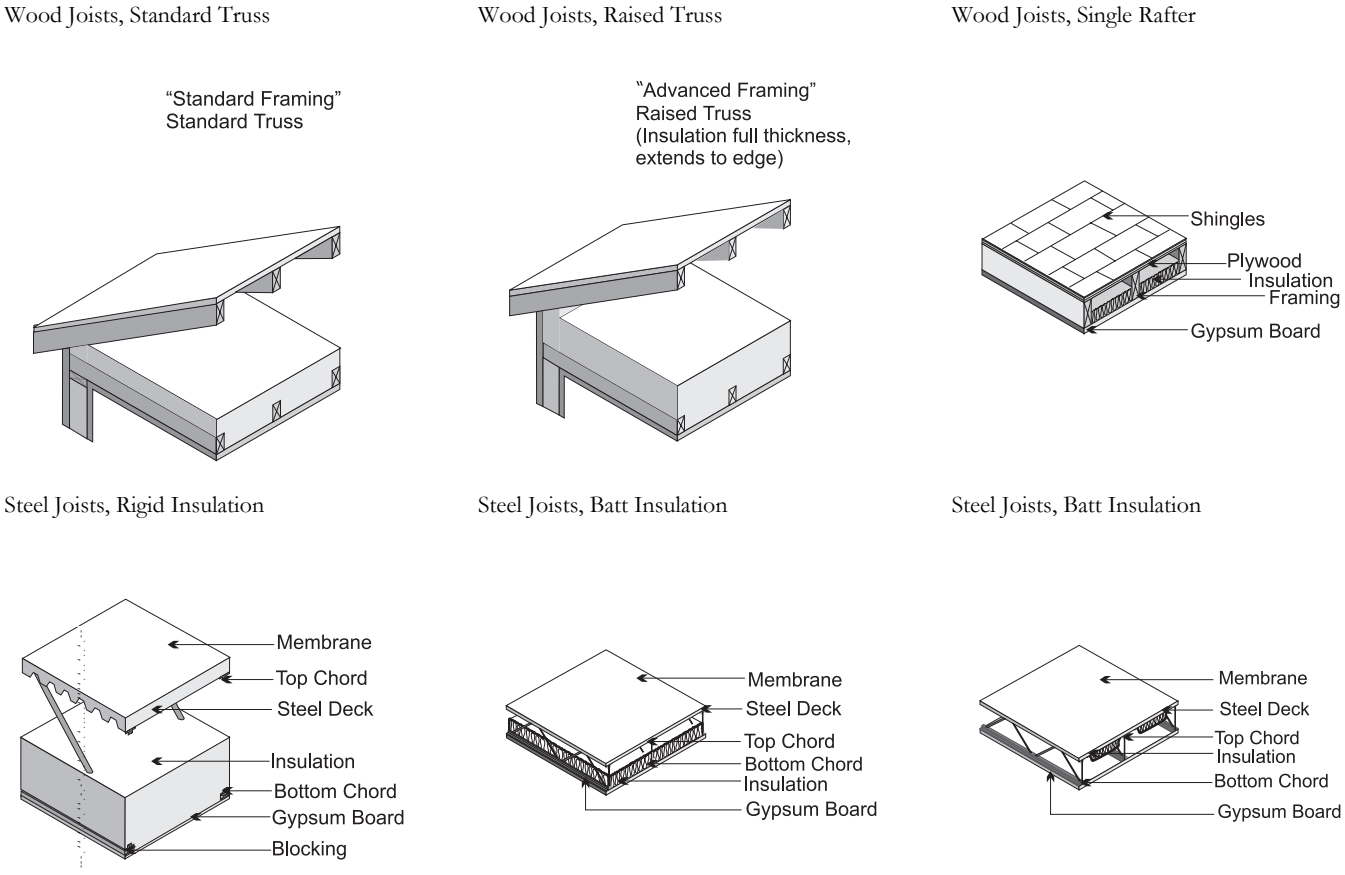

Figure 5-T—Roof, Attic, and Other

Above-Grade Wall Classes (§ A3)
The Standard considers four classes of above-grade wall constructions: mass walls, metal building walls, steel-framed walls, and other walls (mainly wood-framed walls). This section describes the differences between these classes of construction and reviews methods that can be used to determine the U-factor. Information in this section is applicable to both the prescriptive compliance options and the Building Envelope Trade-Off Option.

Usually it is very clear if a wall is above grade or not. However, in some cases, a portion of a wall may be above grade and a portion below grade. When a wall is both above grade and below grade and insulated on the interior, the above-grade insulation requirement applies to the entire wall. In this case, a furring strip is typically installed on the inside of the wall and insulation is installed within the cavity of the furring strip. With this construction technique, it is very easy to insulate the entire wall to the above-grade criterion; in fact, it might cost more to reduce the insulation for the below-grade portion. When the insulation is installed on the exterior of the wall or is integral to the wall (for instance, the cells of a concrete masonry wall are filled), then the wall is divided between the above-grade and below-grade portions and the separate requirements apply to each.

Mass Walls
A mass wall is a wall with a heat capacity (HC) greater than 7.0, or greater than 5.0 if constructed of materials that have a density less than 120 lb/ft³. Use Tables

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A3.1B or A3.1C in the Standard to determine the heat capacity or calculate the heat capacity if the mass wall is not adequately represented in those tables. Figure 5-U shows examples of walls in this class.

Appendix A has several ways to determine the U-factor of mass walls. The easiest method is to use data from Table A3.1A. The table has data for 8-inch thick solid concrete and medium weight concrete masonry unit (CMU) walls. The CMU data are given for solid grouted and partially grouted walls. While the table is based on the mass constructions described above, it can be used for any mass wall as long as the insulation is continuous and has a minimum R-value of 1.0. Ungrouted CMU walls should use data from the partially grouted column. Concrete walls should use the 8-inch concrete column regardless of thickness. The same is true for CMU walls that are not 8-inches thick.

For uninsulated mass walls or mass walls where the insulation is interrupted by framing members or clips, Tables A3.1B, A3.1C, and A3.1D may be used. These tables are a little more complicated to use than Table A3.1A, but they provide considerable flexibility for a wide variety of walls.

- Table A3.1B has data for concrete walls with a thickness ranging from 3 in. to 12 in. and densities ranging from 20 lb/ft³ to 144 lb/ft³. For each case, the table provides an overall U-factor and total R-value (R_w). The overall U-factor may be used directly for compliance if the wall does not have exterior insulation, interior insulation, or interior furring. The table also contains the heat capacity (HC). This value can be used to verify that the wall qualifies as a mass wall. In order to qualify, the HC must be equal to or greater than 7.0 for mass materials that have a density equal to or greater than 120 lb/ft³. HC must be greater than 5.0 for mass materials that have a density less than 120 lb/ft³. Note that not all the constructions in Table A3.1B actually qualify as mass walls. Table A3.1B is used with both above-grade mass walls and below-grade walls. For this reason, it has U-factors and R_w for above-grade walls, and C-factors and R_c for below-grade walls. Be careful which you use in your calculations.
- Table A3.1C has data for concrete masonry unit (CMU) walls with 12 in., 10 in., 8 in., and 6 in. thicknesses and densities ranging from 85 lb/ft³ to 135 lb/ft³. Data are also provided for five different treatments of the cells of the concrete blocks: solid grouted, partially grouted with the cells empty, partially grouted with the cells insulated, unreinforced with the cells empty, and unreinforced with the cells insulated. Partially grouted means that cells are grouted no more than 32 in. o.c. vertically and 48 in. o.c. horizontally. As with Table A3.1B, the table provides the HC and an overall U-factor that may be used directly for compliance if the wall does not have exterior insulation, interior insulation, or an interior furring space.
- Table A3.1D has the effective R-value of insulation/framing layers that may be added to the thermal resistance of the concrete or CMU mass wall selected from Table A3.1B or A3.1C. The table has data for R-values ranging from zero to R-25. The table also has data for metal framing, wood framing, and no framing (continuous insulation). The metal and wood framing can have depths ranging from 0.5 in. and 5.5 in. Data from this table is added to the R_w taken from either Table A3.1B or A3.1C. The sum is the thermal total resistance. The overall U-factor is the reciprocal of the total resistance.

Example 5-S—Concrete Roof with No Insulation

Q

A building in a hot climate has a roof construction that consists of a lightweight concrete over a metal deck. The construction is not insulated, but a roof coating is used that has both a high reflectance and a high emittance. What roof class does this construction fall in?

A

This construction is in the "other" class, since it is not insulated. If it had insulation above the deck, then it would belong to the insulation-entirely-above-deck class. Because of the concrete deck, this construction cannot be a member of the metal building class.

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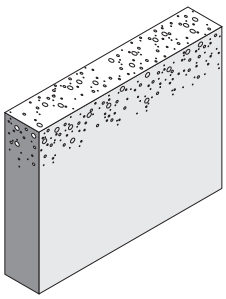
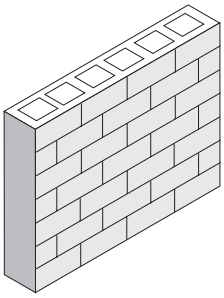
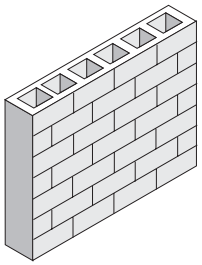
Concrete



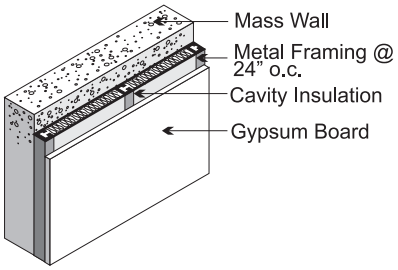
Solid Grouted Concrete Block



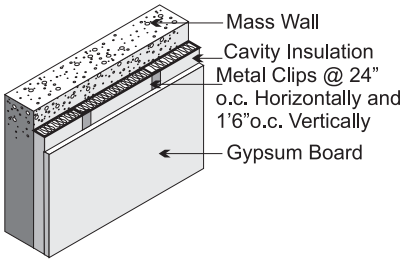
Partially Grouted Concrete Block



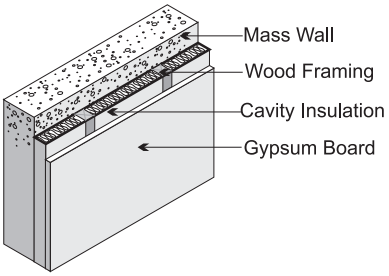
Metal Framing



Metal Clips



Wood Framing



Rigid Insulation

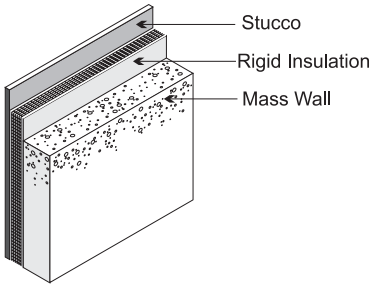


Figure 5-U—Wall, Mass

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Metal Building Walls

Metal building walls are a component of prefabricated metal buildings. The exterior surface and the weather barrier is a metal panel that usually runs vertically. It is attached to horizontal purlins or supports that are spaced at about 4 ft on center. The typical insulation method is to drape batt insulation over the purlins before the metal sheathing is attached. The sheathing then compresses the insulation at the supports. There are other metal building wall systems, but this system is the most common. Figure 5-V shows an example of a wall in this class.

U-factors for metal building walls are to be taken from Table A3.2 of Appendix A of the Standard. This table has data for one and two layers of batt insulation installed on the interior of the metal panel. Data are also provided for continuous insulation installed by itself or in combination with the batt insulation. Because of the complexity of heat transfer in metal building walls, you would have to use a two-dimensional heat transfer model or laboratory testing in order to determine your own U-factor. In the future, perhaps a manufacturer or an industry group might make this available. Until then, Table A3.2 is essentially the only acceptable U-factor available for metal building walls.

Steel-Framed Walls

Steel-framed walls are quite common in nonresidential building construction. Life-safety codes require that many building types be constructed of noncombustible materials, and this means that steel studs are commonly substituted for wood studs. The construction techniques are similar for metal and woods studs. In both cases, an interior finish material (usually gypsum board) is attached to the inside surface. Any number of materials can be used for the exterior finish, including GFRC (glass fiber reinforced concrete), pre-cast concrete, stucco, or glass curtain walls. Steel studs are much more conductive than wood studs, and the economics of providing insulation are quite different. This is the defining characteristic of this class of construction. Figure 5-W shows an example of a wall in this class.

Table A3.3 has U-factor data for both 3.5 in. deep and 5.5 in. deep metal studs spaced at both 16 in. o.c. and 24 in. o.c. Data are also provided for different levels of both cavity insulation and continuous insulation. The cavity insulation is interrupted by the metal framing, while the continuous insulation is not. U-factors in the table include an exterior air film (R-0.17), stucco (R-0.08), exterior gypsum board (R-0.56), interior gypsum board (R-0.56), and an interior air film (R-0.68). The effective R-value of the framing/cavity is taken from Table A9.2B of Appendix A. When using U-factors from Table A3.3, the continuous insulation (if applicable) must be uninterrupted and the cavity insulation (if applicable) must be uncompressed.

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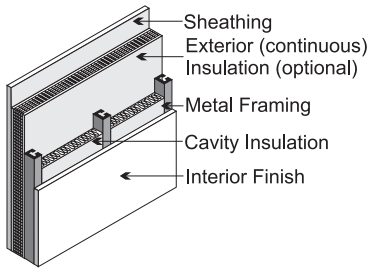

Figure 5-V—Wall, Steel-Framed

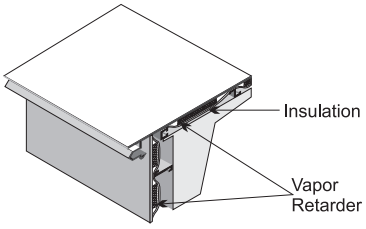

Figure 5-W—Wall, Metal Building

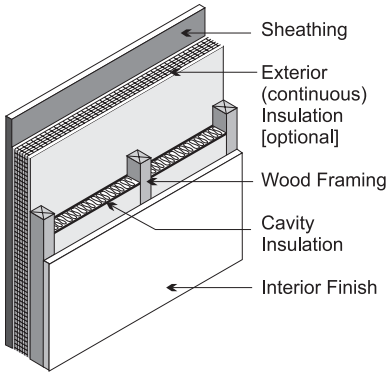

Figure 5-X—Wall, Wood-Framed, and Other

Example 5-T—U-Factor Calculation, Mass Wall

Q

What is the U-factor of a 10 in., solid grouted CMU wall with a block density of 95 lb/ft³? The wall has a furred interior wall with wood framing members that are 3.5 in. deep and R-11 in the cavity.

A

The first step is to find the total thermal resistance of the CMU wall and air films from Table A3.1C. The total thermal resistance (R_u) is 2.15 and the HC is 19.7. The second step is to find the additional thermal resistance from Table A3.1D. For 3.5 in. deep wood studs and R-11, the effective R-value (R_{Eff}) of the framing cavity layer (including the drywall) is 9.3. The overall thermal resistance is 11.45 and the U-factor is 0.087. The details of the calculation are:

$$U = \frac{1}{R_u + R_{Eff}} = \frac{1}{2.15 + 9.3} = \frac{1}{11.45} = 0.087$$

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If your steel-framed wall construction is significantly different from that assumed to develop the values in Table A3.3 (see § A1.2), you can calculate your own U-factor. Appendix A specifies methods for each class of construction and for steel-framed walls. U-factors must be calculated in one of three ways: laboratory tests, the parallel path calculation method using the insulation/framing layer adjustment factors in Table A9.2B, or the modified zone method. The modified zone method is documented in the 2001 *ASHRAE Handbook—Fundamentals*. It is also described in the Reference section of this Manual. The values in Table A9.2B represent effective R-values and were derived from laboratory tests. An effective R-value is the thermal resistance that may be added to the thermal resistance of the other layers in the wall that results in the correct heat transfer. When the heat transfer is determined through laboratory tests and the thermal resistance of all the other layers is known, the effective R-value of the framing/cavity layer can be calculated with simple algebra. This is the basis of the values in Table A3.3.

Wood-Framed and Other Walls

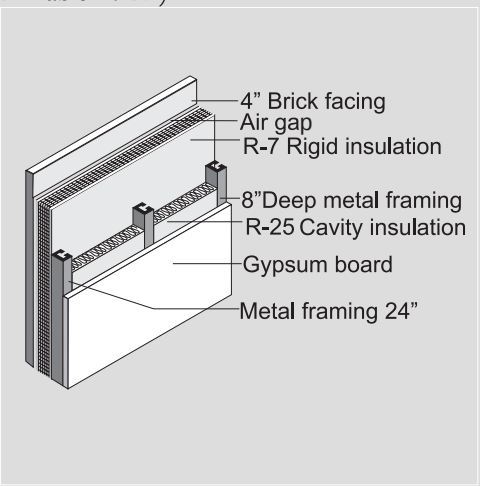
This class of construction includes wood-framed walls but also all wall constructions that do not qualify for one of the other classifications. Figure 5-X shows an example of a wall in this class.

Table A3.4 has pre-calculated U-factor data that are to be used for wood-framed walls. This table is organized by the wood stud spacing (either 24 in. or 16 in. o.c.) and by the depth of the stud (either 3.5 in. or 5.5 in.). For the 5.5 in. stud depth case, there is also an option for insulated headers (+ R-10 headers). Headers are the horizontal supports over doors and windows. Normally these are constructed of solid wood, which is more conductive than the insulated cavities. With the R-10

Example 5-U—U-Factor Calculation, Steel-Framed Wall, Effective R-Value Method

Q

What is the U-factor of the steel-framed wall represented in the following sketch? The wall has exterior face brick, an air gap, R-7 rigid insulation, a framing/cavity layer and interior gypsum board. The metal framing is 8 in. deep and is spaced at 24 in. o.c. R-25 insulation is installed in the cavity. (Hint: use the parallel path calculation method and effective R-values from Table A9.2B).



A

The parallel path calculation method is used as shown below. The thermal resistance of each layer of the construction assembly is listed, including the framing/cavity layer. The effective R-value of the framing/cavity layer is 9.6 from Table A9.2B. This is added to the thermal resistance of the other layers as shown below.

Layer	R-value	Source of Data
Exterior air film	0.17	*Standard 90.1-2007* (§ A9.4.1)
4 in. face brick	0.25	*ASHRAE Handbook*
0.75 in. air space	0.90	*Standard 90.1-2007* (Table A9.4A)
Rigid insulation	7.00	Manufacturer's data
0.625 in. gypsum board	0.56	*Standard 90.1-2007* (Table A9.4D)
Framing/cavity	9.60	*Standard 90.1-2007* (Table A9.2B)
0.625 in gypsum board	0.56	*Standard 90.1-2007* (Table A9.4D)
Interior air film	0.68	*Standard 90.1-2007* (§ A9.4.1)
Total	*19.72*	
U-factor	*0.051*	

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Table 5-I—Framing Percentages for Wood-Framed Walls

	Insulated Cavity	*Studs*	*Headers*
Standard Framing (16 in. o.c.)	75	21	4
Advanced Framing (24 in. o.c.)	78	18	4
Advanced with Insulated Headers	78	18	4

header option, the header is also insulated by sandwiching 2.5 in. of rigid insulation between 1.5 in. framing members. Table A3.4 has data for insulation installed in the cavity and insulation installed in a continuous manner and uninterrupted by the framing members. The continuous insulation can be installed on either the interior or the exterior of the wall. You can select any combination of cavity and continuous insulation and the table provides the correct U-factor.

Constructions in the table include an exterior air film, stucco, exterior gypsum board, the framing/cavity layer, interior gypsum board, and an interior air film. The calculations are done using the parallel path calculation method. The percent of the wall that is assumed to be insulated cavity, studs and headers is shown in Table 5-I.

For walls that are constructed significantly differently from the assumptions used to generate Table A3.4 (as defined in § A1.2), you can calculate your own U-factor. There are a number of calculation options for wood-framed walls, including laboratory tests and parallel path calculation methods. With the parallel path calculation method, the wall is divided into sub-areas. For wood-framed walls, the sub-areas are typically the insulated cavity, the portion that is solid wood studs and the portion that is a header (the horizontal members that span over doors and windows). Heat is assumed to flow straight across the wall. The heat that passes through each sub-area is directly proportional to the area of that wall and its U-factor. The overall U-factor of the wall is the area-weighted average of the U-factors through the sub-areas. Example 5-V shows how this calculation is performed.

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Below-Grade Wall Classes (§ A4)
Below-grade walls have conditioned or semiheated space on one side and earth on the other. Table A4.2 of Appendix A contains C-factors for below-grade walls. The table has data for three conditions:

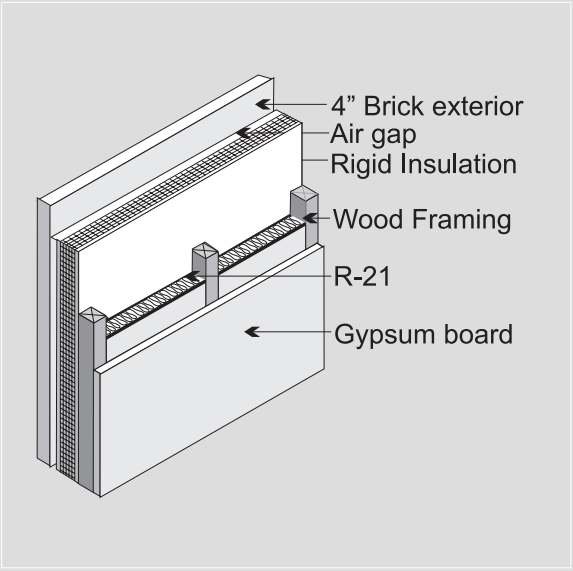
- The first condition is for insulation that is continuous and uninterrupted by framing members of any kind. This will likely be achieved by installing the insulation on the outside of the below-grade wall and backfilling with earth.
- The second condition is for insulation installed between steel framing members or studs that are spaced at 24 in. o.c. This will typically be achieved by furring the inside wall and installing insulation in the cavity created by the steel studs.
- The third condition is metal clips that are spaced at 24 in. o.c. horizontally and 16 in. o.c. horizontally. These are generally Z-clips used to support the insulation and to attach the interior finish material (usually gypsum board). This system performs better than standard steel studs because there is much less metal to provide a thermal bridge past the insulation.

For each condition, Table A4.2 gives the C-factor for varying levels of insulation R-value. The C-factor does not include the air films or the effect of the earth. Since the conditions of the earth are so varied, a C-factor is a far better figure of merit for below-grade walls than a U-factor. The values in Table A4.2 are based on an 8 in. solid grouted concrete masonry unit (CMU) wall; however, the C-factors in the table can be used for any below-grade wall. For insulated walls, the thermal resistance of 0.5-in. thick gypsum board is also assumed (R-0.45).

Example 5-V—U-Factor Calculation, Wood-Framed Wall, Parallel Path Calculation Method

Q

Use the parallel path method to calculate the U-factor of the wood-framed wall represented in the following sketch.



A

With the parallel path method, the wall is divided into three parts: the portion that is insulated cavity, the portion that is solid wood framing (the studs), and the portion that is a header. The cavity is assumed to represent 78% of the wall area, the studs 18%, and the headers 4%. These are the assumptions that were used to generate the values in Table A3.4 and are acceptable defaults when you make your own calculations. The next step is to make a list of all the different materials or layers through the wall. Some layers—such as the face brick—are common to all sub-areas. Others—such as the cavity insulation—are unique to a particular sub-area. The thermal resistance of building materials can be taken from Table A9.4D of the Standard, the ASHRAE *Handbook*, or from test data. Build a table with three columns for each sub-area as shown on page 5-66. If a material does not apply, enter "n.a."

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The C-factor can also be calculated using the data in Table A3.1B, A3.1C and A3.1D. The procedure is similar to that described for above-grade mass walls. This procedure is a little more complicated than just finding values from Table A4.2, but it provides considerable flexibility for a wide variety of walls.

- *Table A3.1B* has data for concrete walls with a thickness ranging from 3 in. to 12 in. and densities ranging from 20 lb/ft³ to 144 lb/ft³. For each case, the table provides a C-factor and total R-value (R_t) that excludes the air films and earth. Table A3.1B is used with both above-grade mass walls and below-grade walls. For this reason, it has U-factors and R_u for above-grade walls and C-factors and R_c for below-grade walls. Be careful which you use in your calculations. The C-factor may be used directly for compliance if the below-grade wall does not have exterior insulation, interior insulation, or interior furring.
- *Table A3.1C* has data for concrete masonry unit (CMU) walls with 12 in., 10 in., 8 in., and 6 in. thicknesses and densities ranging from 85 lb/ft³ to 135 lb/ft³. Data are also provided for five different treatments of the cells of the concrete blocks: solid grouted, partially grouted with the cells empty, partially grouted with the cells insulated, unreinforced with the cells empty, and unreinforced with the cells insulated. Partially grouted means that cells are grouted no more than 32 in. o.c. vertically and 48 in. o.c. horizontally. As with Table A3.1B, the C-factor may be used directly for compliance if the wall does not have exterior insulation, interior insulation, or an interior furring space. The total R-value (R_c) is also provided, which excludes the air films and the soil.
- *Table A3.1D* has the effective R-value of insulation/framing layers that may be added to the thermal resistance

Example 5-R—U-Factor Calculation, Wood-Framed Wall, Parallel Path Calculation Method *[continued]*

	Cavity	Studs	Headers	Data Source
Exterior air film	0.17	0.17	0.17	*Standard 90.1-2007* (§ A9.4.1)
4 in. face brick	0.25	0.25	0.25	ASHRAE *Handbook*
0.75 in. air space	0.90	0.90	0.90	*Standard 90.1-2007* (Table A9.4A)
Rigid insulation	7.00	7.00	7.00	Manufacturer's data
0.625 in. gypsum board	0.56	0.56	0.56	*Standard 90.1-2007* (Table A9.4D)
Cavity insulation	25.00	n.a.	n.a.	Manufacturer's data
Wood studs	n.a.	9.06	n.a.	*Standard 90.1-2007* (Table A9.4D)
Wood header	n.a.	n.a.	1.88	ASHRAE *Handbook*
Rigid insulation	n.a.	n.a.	17.50	Manufacturer's data
Wood header	n.a.	n.a.	1.88	ASHRAE *Handbook*
0.625 in. gypsum board	0.56	0.56	0.56	*Standard 90.1-2007* (Table A9.4D)
Interior air film	0.68	0.68	0.68	*Standard 90.1-2007* (§ A9.4.1)
Total thermal resistance	35.12	18.18	31.38	
U-factor	0.0285	0.0521	0.0319	
Weight	78%	18%	4%	

The next step is to calculate the thermal resistance through each sub-area of the wall. This is the sum of each thermal resistance in each parallel path to heat flow. The total thermal resistance is 35.12 through the cavity, 18.18 through the studs, and 31.38 through the header. The U-factor through each sub-area is the reciprocal of the total thermal resistance or one divided by the total thermal resistance. The U-factor is 0.0285 through the cavity, 0.0521 through the studs, and 0.0319 through the header.

The final step is to do an area-weighted average of the U-factors to determine the overall U-factor. The overall U-factor is 0.0329 as calculated below.

$$U_{Overall} = W_{Cavity} \times U_{Cavity} + W_{Studs} \times U_{Studs} + W_{Header} \times U_{Header}$$

$$U_{Overall} = 0.78 \times 0.0285 + 0.18 \times 0.0521 + 0.04 \times 0.0319$$

$$U_{Overall} = 0.0329$$

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(R_c) of the concrete or CMU mass wall selected from Table A3.1B or A3.1C. Table A3.1D has data for R-values ranging from zero to R-25. The table also has data for metal framing, wood framing, and no framing (continuous insulation). The metal and wood framing can have depths ranging from 0.5 in. and 5.5 in. Data from this table are added to the R_c taken from either Table A3.1B or A3.1C. The sum is the total thermal resistance (excluding air films and soil). The overall C-factor is the reciprocal of this total resistance. A C-factor calculation is shown in Example 5-W.

Floor Classes (§ A5)

The Standard considers three classes of floor constructions: mass floors, steel-joist floors, and wood-framed and other floors. This section describes the differences between these classes of construction and reviews methods that can be used to determine the U-factor. Information in this section is applicable to both the prescriptive compliance options and the Building Envelope Trade-Off Option.

Mass Floors

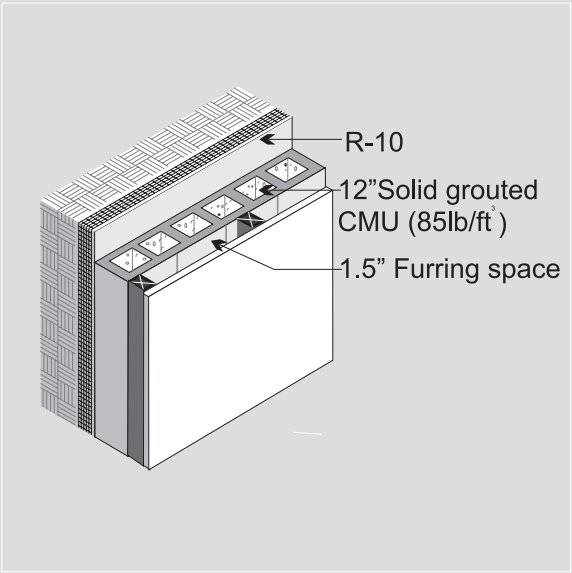
Mass floors are floors that have a heat capacity (HC) greater than 7.0. If they are constructed of lightweight concrete with a density less than 120 lb/ft³, the floors qualify as mass floors if the HC is greater than 5.0. Use Table A3.1B and A3.1C to determine HC. You can also calculate HC yourself if the assembly is not adequately represented in those tables (see Heat Capacity in the Reference section).

Table A5.2 has U-factors for mass floors. The table takes account of continuous insulation, spray-on insulation, and pinned batt insulation. In all cases, the insulation is assumed continuous; this is a restriction on the use of this table. Development of the data in A5.2 assumes

Example 5-W—C-Factor Calculation, Below-Grade Wall

Q

What is the C-factor of a 12 in., solid grouted CMU wall with a block density of 85 lb/ft³? The wall has continuous exterior insulation with a thermal resistance of R-10 and interior furring with no insulation. The furring space is 1.5 in. deep and the furring members are constructed of wood.



A

The first step is to find the thermal resistance (R_c) of the CMU wall from Table A3.1C. The total thermal resistance (R_c) is 1.68.

The second step is to find the additional thermal resistances from Table A3.1D. The thermal resistance of the exterior insulation is R-10 (from above figure). R-10 should be used rather than the 10.5 that is listed in Table A3.1D; otherwise, the resistance of the drywall (gypsum board) would be double counted. The thermal resistance of the interior furring space is 1.3 (see Table A3.1D). The overall thermal resistance is 12.98 and the U-factor is 0.077. The details of the calculation are:

$$U = \frac{1}{R_c + R_{Ext} + R_{Furring}} = \frac{1}{1.68 + 10 + 1.3} = \frac{1}{12.98} = 0.077$$

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an inside film resistance (R-0.92), carpet and rubber pad (R-1.23), 8 in. of concrete (R-0.50), and a semi-exterior air film (R-0.46). Insulation specified in the table is added to these base thermal resistances.

Table A5.2 may not be used if framing members of any kind interrupt the continuity of the mass floor insulation. For these types of floor systems, you can calculate your own U-factor, but you must use advanced calculation techniques. The U-factor must be determined with laboratory tests, two-dimensional heat transfer analysis, or by using isothermal planes (e.g., the series method with data from Table A9.2A). Example 5-X shows how the U-factor is determined for a concrete floor on steel supports.

Steel Joist Floors

Steel joist floors are floors supported by steel bar joists or purlins that do not qualify as mass floors. Use Table A5.3 of Appendix A to determine the U-factor of steel-joist floors. This table may be used with any type of steel-joist floor; however, the values are based on an inside air film (R-0.92), a carpet and rubber pad (R-1.23), and a semi-exterior air film (R-0.46). The thermal resistance of the assumed metal deck and concrete topping is ignored. The table has data for insulation sprayed to the bottom surface of the deck and for insulating batts pinned or otherwise fastened to the underside of the deck. Continuous insulation can be added in addition to one of these options. When calculating the U-factor (if allowed by § A1.2), you must use either laboratory testing or the modified zone method. Example 5-Y shows how the U-factor is determined for a steel-joist floor.

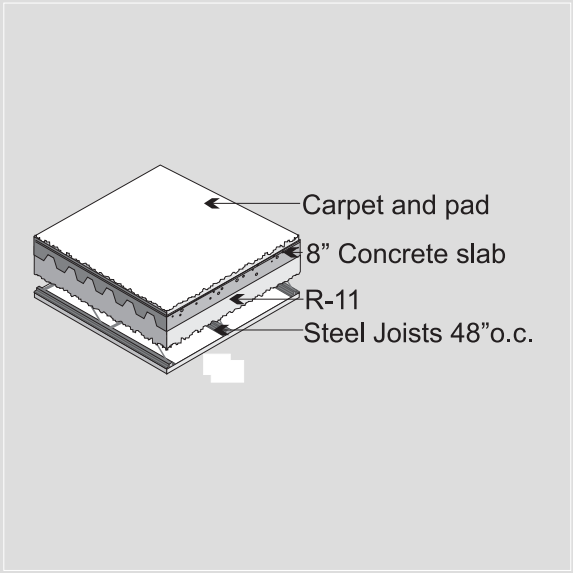
Wood-Framed and Other Floors

This class includes all floor constructions that do not qualify as mass or metal-framed floors. For wood-framed floors,

Example 5-X—U-Factor Calculation, Concrete Floor on Steel Supports

Q

What is the U-factor of the mass floor represented in the following sketch? The floor consists of an 8 in. reinforced concrete slab (density 105 lb/ft³) supported by steel joists located at 48 in. o.c. The underside of the floor is insulated with R-11 spray-on insulation.



A

Layer	R-value	Data Source
Inside air film	0.92	§ A9.4.1
Carpet and pad	1.23	Table A9.4D
0.5 in. concrete (85 lb/ft³)	0.35	Table A3.1B (use Rc / 2)
8.0 in. concrete (144 lb/ft³)	0.50	Table A3.1B (use Rc)
Insulation/framing	10.01	Table A9.2A
Semi-exterior air film	0.46	§ A9.4.1
Total R-value	13.47	
U-factor	0.0742	

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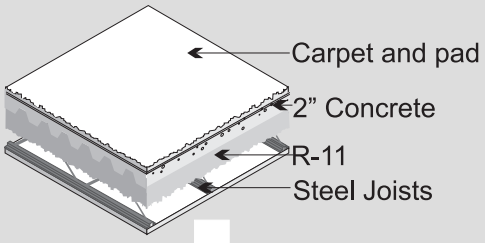
Table A5.4 of Appendix A has U-factors that are to be used with the U-factor prescriptive option or with the envelope trade-off option. Values in this table assume an inside air film (R-0.92), a carpet and pad (R-1.23), a 0.75 in. thick wood subfloor (R-0.94), and a semi-exterior air film (R-0.46). The assumption is that 91% of the floor is insulated cavity and 9% is solid wood framing. Table A5.4 has data for insulation that is located in the cavity ranging from none to R-38. The table also accounts for the depth of the floor joists, but not the spacing; the table can be used with any joist spacing. The table also has data when continuous insulation is applied in addition to or instead of insulation in the framing cavity.

When you need to calculate U-factors (if allowed by § A1.2), you may use laboratory tests or the parallel path calculation method. Laboratory tests are not a practical solution for most construction projects, but the parallel path method is easy to use and well understood by most architects and engineers. Example 5-Z shows how the parallel path calculation method can be applied to wood floors.

Example 5-Y—U-Factor Calculation, Steel Joist Floor

Q

What is the U-factor of the steel-joist floor construction represented in the following sketch? Determine the value in two ways. First, look up data from Table A5.3. Second, calculate the value using the series calculation method and the effective R-values from Table A9.2A. The construction has a carpet and rubber pad, 2 inches of lightweight concrete, a metal deck, and spray-on insulation having an R-value of R-11.



A

The U-factor determined from Table A5.3 of Appendix A is 0.079. As Table A5.3 does not contain R-11 spray-on insulation, it is necessary to interpolate, which is allowed by § A1.1. The U-factor for R-8 spray-on insulation is 0.096 and the U-factor for R-12 spray-on insulation is 0.073. Interpolation for R-11 results in a U-factor of 0.79.
The series calculation method can also be used with the effective R-values from Table A9.2A. The U-factor determined from this method is 0.0784 as shown below.

Layer	R-value	Data Source
Inside air film	0.61	§ A9.4.1
Carpet and pad	1.22	Table A9.4D
2 in. lightweight concrete (85 lb/ft³)	0.46	Table A3.1B
(take half of Rc for 4 in.)		
Effective R-value	10.01	Table A9.2A
Semi-exterior air film	0.46	§ A9.4.1
Total R-value	12.76	
U-factor	0.0784	

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Table 5-J—U-Factors for Unlabeled Doors

	U-*factor*	
Construction Description	*Btu/h·ft²·°F*	*W/m²·°C*
(a) Uninsulated single-layer metal swinging doors or non-swinging doors, including single-layer uninsulated access hatches and uninsulated smoke vents	1.45	8.2
(b) Uninsulated double-layer metal swinging doors or non-swinging doors, including double-layer uninsulated access hatches and uninsulated smoke vents	0.70	4.0
(c) Insulated metal swinging doors, including fire-rated doors, insulated access hatches, and insulated smoke vents	0.50	2.8
(d) Wood doors, minimum nominal thickness of 1 3/4 in. (44 mm), including panel doors with minimum panel thickness of 1 1/8 in. (28 mm), and solid core flush doors, and hollow core flush doors	0.50	2.8
(e) Any other wood door	0.60	3.4

Slab-on-Grade Floor Classes (§ A6)
Slab-on-grade floors are in direct contact with the earth. They are generally made of concrete and can have several edge conditions (see Figure 5-K). Table A6.3 of Appendix A has F-factors for various combinations of insulation R-value and insulation depths and configurations. Using this table in conjunction with the F-factor criteria is a flexible way of meeting the requirements. Heat loss through concrete slabs is complex and the only method to determine F-factors is to use the data in Table A6.3.

Opaque Door Classes (§ A7)
U-factors for opaque doors are to be determined in accordance with NFRC procedures. The NFRC process for rating and labeling doors is similar to that used for fenestration. NFRC *Standard 100* applies to doors in the same manner that it applies to windows. When doors have NFRC ratings, the U-factor from the rating shall be used for compliance. For unlabeled doors, § A7 of Appendix A prescribes the U-factors to use. These are summarized in Table 5-J.

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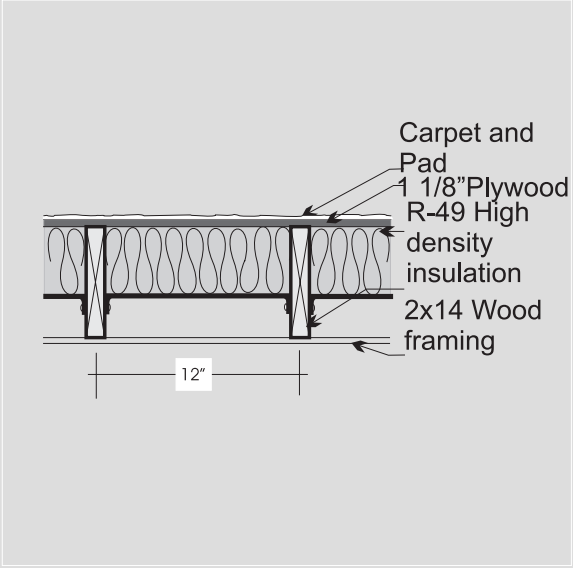
Example 5-Z—U-Factor Calculation, Wood-Framed Floor

Q

What is the U-factor of the wood-framed floor represented in the following sketch? Determine the U-factor by using Table A5.4. Also, calculate the U-factor using the parallel path method. The floor has a carpet and pad, 1 ⅛ in. plywood, 2x14 wood joists at 12 in. o. c., R-49 high-density insulation in the cavity between the joists, and ⅝ in. gypsum board ceiling.



A

Table A5.4 does not list this case so the parallel path method should be used. The U-factor from this method is 0.0222, as shown below:

Layer	Cavity	Framing	Data Source
Percent of floor	91%	9%	
Inside air film	0.6100	0.6100	*Standard 90.1-2007* (§ A9.4.1)
Carpet and pad	1.2300	1.2300	*Standard 90.1-2007* (Table A9.4D)
Insulation (high density)	49.0000	n.a.	Manufacturer's data
2 x 14 wood joists	n.a.	16.5600	*Standard 90.1-2007* (Table A9.4D)
Gypsum board	0.5600	0.5600	*Standard 90.1-2007* (Table A9.4D)
Semi-exterior air film	0.4600	0.4600	*Standard 90.1-2007* (§ A9.4.1)
Total R-value	51.8600	19.4200	
U-factor	0.0193	0.0515	
Weighted Average =	0.0222		

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Compliance Forms

Instructions

Compliance forms are provided in the User's Manual to assist in understanding and documenting compliance with the building envelope requirements. Copies of the forms are provided both in printed and electronic form. Modifiable electronic versions are included on the CD distributed with the Manual, and also available for download from the ASHRAE website.

The building envelope forms are organized in two parts and on three pages. Part I should be used with all methods of compliance. Part II should be used only with the Prescriptive Building Envelope Option and should be completed separately for each space-conditioning category in the building.

- Part I has header information and a Mandatory Provisions checklist. This page should be filled out for all compliance methods, since the mandatory features apply to all compliance methods.
- Part II, Page 1 has header information that must be completed for each space-conditioning category and a schedule of constructions for opaque surfaces. The schedule is a simple listing of each unique construction type in the building. For each item in the list, you indicate the class of construction, the source of U-factor data, the proposed and criteria U-factor or R-value. Optionally, you may enter the surface area of the building for this construction type.
- Part II, Page 2 of the documentation is a schedule of fenestration construction types. This table contains an item for each unique fenestration construction type. For each item in the table, you indicate the class of construction, the source of data, proposed fenestration data and the performance criteria.

Part I: Header Information

Project Name: Enter the name of the project. This should agree with the name that is used on the plans and specifications or the common name used to refer to the project.

Project Address: Enter the street address of the project, for instance "142 Minna Street."

Date: Enter the date when the compliance documentation was completed.

Designer of Record/Telephone: Enter the name and the telephone number of the designer of record for the project. This will generally be an architecture firm.

Contact Person/Telephone: Enter the name and telephone number of the person who should be contacted if there are questions about the compliance documentation.

City: The name of the city where the project is located.

Climate Zone: The climate zone of this project.

Criteria Table: Enter the number of the criteria table used for the project (for example, 5.5-4). Look in Table 5.5-1 through Table 5.5-8 for the criteria tables for all climate locations. If your county or city is listed in the Standard's Appendix B, the appropriate criteria table will be shown next to your city.

Part I: Mandatory Provisions Checklist

This section of the compliance form summarizes the mandatory requirements for the design of the building envelope. The mandatory measures are organized on this form in the same order as they are in the Standard: Insulation, Fenestration and Doors and Air Leakage. Checking a box indicates that the mandatory requirement applies to the building and that the building complies with the requirement. If the requirement is not applicable, leave the box unchecked.

Part II: Header Information

Part II is used with the Prescriptive Building Envelope Option. A separate Part II form should be completed for each space-conditioning category in the building. The Project Name, Contact Person and Telephone should be carried over from Part I. The following additional information is required.

Space Category: Check one of the option buttons to indicate the space-conditioning category for the opaque constructions and fenestration constructions that follow.

5.3.2.3 Exceptions: This section has checkboxes for you to indicate which fenestration exceptions you are using. Three exceptions are available:

- *Overhangs*: When this exception is taken, the shading effect of overhangs can be used to adjust the proposed building's SHGC. This exception can be taken on a window-by-window basis. This box should be checked if an overhang credit is taken for any window.
- *Street Level Windows:* When this exception is taken, street level windows are exempt from the SHGC criteria, provided they do not exceed 75% of the gross wall area, the street level floor-to-floor height does not exceed 20 ft, and the street level fenestration is shaded by an

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overhang that has a projection factor of at least 0.5. With this exception, the street level wall area and window area that qualify for the exception are ignored in the remaining window-wall ratio calculations.

Window-Wall Ratio: Enter the gross wall area, the total window anea and calculate the window wall ratio. This value must be less than 40% The following bullets describe the information to be entered.

- *Gross Wall Area (ft²):* Sum the gross exterior wall area for the space-conditioning category. Only include exterior walls in this summation; do not include semi-exterior walls or interior partitions. The gross wall area includes windows and doors. If you group exterior walls together when you complete Part II: Opaque Surfaces, then this form can be a useful aid in summing the exterior wall area.
- *Window Area (ft²):* Sum the window area for the exterior walls in the space-conditioning category. Window area should include the frame as well as the glazed area. If you group windows together when you complete Part II – Fenestration, then this form can be a useful aid in summing the window area.
- *Window-Wall Ratio:* Divide the Window Area by the Gross Wall Area and enter the result in this box. When using the Prescriptive Building Envelope Option, the window-wall ratio must be less than 0.40.

Skylight Roof Ratio: This portion of the form should be completed if the space-conditioning category has skylights.

1. Gross Roof Area (ft²). Sum the gross area of all exterior roofs for the space-conditioning category. The gross area should include openings in the roof such as skylights and roof hatches. If you group roofs together when you complete Part II – Opaque Surfaces, then this form can be a useful aid in summing the roof area.

2. Skylight Area (ft²). Sum the skylight area for the space-conditioning category. The skylight area should include the area of the frame. If you group windows together when you complete Part II – Fenestration, then this form can be a useful aid in summing the skylight area.

3. Skylight Roof Ratio. Calculate the skylight-roof ratio by dividing the skylight area by the gross roof area and enter the result in this box. When using the Prescriptive Building Envelope Option, the skylight-roof ratio must be less than 0.05.

Part II: Opaque Surfaces

This portion of Part II summarizes all opaque construction types for the space-conditioning category. An entry should be made in the table for each unique construction. The Part II – Header Information requires data on the exterior wall and roof area, so at a minimum, roofs and exterior walls should be grouped together. The Opaque Surfaces form can be used to make these calculations if you group surface types together and use the optional Surface Area column. Finally, you may also want to group constructions for each class if you want to perform area-weighted averaging. The Standard permits proposed area-weighted average U-factor to be compared to the criteria, but only within each class of construction.

The following paragraphs describe the information to be entered on this form.

Description/Name: Enter a name for each construction or enter the code used on the drawings and specifications. When the drawings and specifications already have a schedule of constructions, the names or codes should be consistent between the compliance forms and the plans and specifications.

Class: Choose the surface type and class by marking one (and only one) column. This information is used to determine the criteria for the opaque construction.

R-Value/U-Factor Option: Mark the method used for compliance for this construction. The prescriptive tables give the criteria both as a minimum insulation R-value and a maximum U-factor. For below-grade walls, the maximum U-factor is replaced with a maximum C-factor. For slabs, the U-factor is replaced with an F-factor. The R-value method is the simplest approach; you only need to document that the insulation in the construction assembly has the required thermal resistance.

Source of U-Factor Data: If Appendix A is the source of the U-factor or C-factor data, mark "Appendix A Defaults". F-factors can only be taken from Appendix A of the Standard, so this is the only possible choice for slabs. If you have calculated the U-factor or C-factor, mark "Calculations." Note that restrictions apply when you calculate your own U-factors or C-factors. Basically, your construction must be significantly different from any of those already contained in Appendix A.

High Reflectance/Emittance Roof: This column only applies to roofs that do not have attics, are located in climate zones 1, 2 or 3 and are cooled spaces. If the exterior surface of the roof has a reflectance greater than 0.70 and an emittance greater than 0.75 or if the roof has a SRI greater than 0.82, then the U-factor of the proposed design can be modified (lowered) to account for surface characteristics of the roof. This is an exception in the Standard and is limited to hot climates that have heating degree-days at base 65ºF that are less than or equal to 3600.

Proposed Insulation R-Value, U-Factor, C-Factor, or F-Factor: Enter the thermal performance of the construction shown on the plans and specifications. If the R-value option is used, then the R-value of

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the insulation should be entered in this column. For some construction types, framed walls for instance, insulation can be placed in the cavity but it can also be applied in a continuous manner on the exterior or interior of the framing. In these instances, both R-values should be entered, e.g., "R-13 + R-4 ci." This notation means that R-13 is installed in the cavity and R-4 is installed in a continuous manner. For continuous insulation, the "ci" subscript should be used to distinguish it from cavity insulation.

If the U-factor, C-factor or F-factor method is used then the value should be taken from Appendix A of the Standard or calculated using an acceptable method, as defined in Appendix A. C-factor is used for below-grade walls; F-factor for slabs; and U-factor for other constructions.

Criteria Insulation R-value, U-factor, C-factor, or F-factor: Enter the required thermal performance of the construction. The criteria are taken from the prescriptive table for the location. The data entered should be consistent with the data entered for the proposed design. If the R-value method is used, then the criteria R-value should be entered. If the U-factor method is used, then the U-factor, C-factor or R-factor should be entered. In either case, completing this column is simply a matter of copying information from the criteria table to the compliance form.

Please note that if a roof surface qualifies as a high reflectance/emittance roof, the criteria value is taken from Table 5.5.3.1 instead of the climate dependent criteria tables. See the roof prescriptive requirements section for details on what qualifies as a high reflectance/emittance roof.

Surface Area (ft^2). This column is optional, but useful in summing wall and roof areas, which are needed for the Part II: Header Information. At a minimum, roofs and exterior walls should be grouped together so that the total area can be summed and entered in the header.

Part II: Fenestration

This portion of the form is a schedule of each fenestration construction in the building. Skylights and windows should be grouped separately in the list by since the area of each of these types of constructions must be summed and entered in Part II—Header Information. If you are taking the overhang exception (calculating an adjusted SHGC to account for the shading effect of overhangs), then you must make separate entries in the table for each window with different overhang dimensions.

Description/Name: Enter a name for each fenestration or enter the code used on the drawings and specifications. When the drawings and specifications already have a schedule of windows, doors, and/or skylights, the names or codes should be consistent between the compliance forms and the plans and specifications.

Class: Choose the vertical fenestration frame type or the skylight class by marking one (and only one) column. This information is used to determine the fenestration criteria.

Source of Data: Indicate the source of the performance data for the proposed fenestration. For fenestration, the performance data must either be taken from NFRC ratings or from Appendix A of the Standard. The Standard permits you to take U-factor data from Appendix A but take SHGC and visible light transmission data from manufacturers' literature. When this is the case, mark Appendix A as the source of data.

Area: Enter the area of the proposed fenestration. The area should include the area of the frame as well as the glazing, since the NFRC performance ratings apply to the total area. Separately group skylights and windows and leave a few blank rows at the end of each grouping so that the area of that group can be summed.

U-Factor: Enter the U-factor of the fenestration. This value should be taken either from NFRC ratings or from Table A8.1A or A8.2 of the Standard. However, Table A8.1A can only be used for unlabeled skylights.

SHGC: Enter the solar heat gain coefficient the fenestration. If you are using an NFRC-rated window, the SHGC is included as part of the rating, and this value should be entered on the compliance form. If you are using Tables A8.1A or A8.2 for U-factor data, then Table A8.1B can be used as the source of SHGC. However, the data in Table A8.1B is limited to only a few types of glazing types. As an alternative, you can take the SHGC from the manufacturer's literature and use this for compliance purposes (see § A8 of the Standard for more information and limitations on this approach).

Overhang: If an overhang shades the window, make a check in this box. Otherwise, leave the box unchecked. The box should remain unchecked for all skylights, since overhangs cannot shade skylights. In order to qualify for this credit, overhangs must be constructed so that they last as long as the building.

Projection Factor: If an overhang shades the window, enter the overhang projection factor for the window. The projection factor is the ratio of the horizontal distance that the overhang projects from the surface of the window to the vertical distance from the windowsill to the bottom of the overhang. This column is not applicable to skylights.

Overhang Multiplier: If an overhand shades the window, enter the overhang multiplier. This is taken from Table

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5.5.4.4.1 of the Standard and depends on the overhang projection factor and the orientation of the window. Table 5.5.4.4.1 has only two orientation categories: north and other. North-oriented windows are those that face within 45 degrees of true north (not magnetic north). This column is not applicable to skylights.

Adjusted SHGC: Calculate and enter the adjusted SHGC by multiplying the SHGC of the unshaded window by the overhang multiplier. This column is not applicable to skylights.

Criteria U-Factor: Enter the criteria U-factor for the fenestration by selecting the appropriate criterion from the criteria table. The U-factor criterion depends on the the frame type class for windows and the class and the skylight-roof ratio for skylights. The proposed U-factor must be less than or equal to the criterion.

Criteria SHGC: Enter the SHGC criterion for the fenestration by selecting the appropriate criterion from the criteria table. The SHGC criterion depends frame type class for windows and the class and the skylight-roof ratio for skylights. The proposed SHGC (or adjusted SHGC) must be less than or equal to the criterion.

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Building Envelope Compliance Documentation Part I

Project Name:		
Project Address:		Date:
Designer of Record:		Telephone:
Contact Person:		Telephone:
City:	Climate Zone:	Criteria Table:

Mandatory Provisions Checklist

Insulation (§ 5.4.1)

- ❑ Insulation Materials are installed in accordance with manufacturer's recommendations and in such a manner as to achieve rated R-value of insulation
  - ❑ Exception: for metal building roofs or metal building walls.
- ❑ Loose-fill insulation is not used in attic roof spaces when the slope of the ceiling is more than three in twelve.
- ❑ Attic eave vents have baffling to deflect the incoming air above the surface of the insulation.
- ❑ Insulation is installed in a permanent manner in substantial contact with the inside surface.
- ❑ Batt insulation installed in floor cavities is supported in a permanent manner by supports no greater than 24 in. o.c.
- ❑ Lighting fixtures, HVAC, and other equipment are not be recessed in ceilings in such a manner to affect the insulation thickness unless.

Exceptions:

- ❑ The recessed area is less than one percent.
- ❑ The entire roof, wall, or floor is covered with insulation to the full depth required.
- ❑ The effects of reduced insulation are included in calculations using an area weighted averages.

- ❑ Roof insulation is not installed over suspended ceiling with removable ceiling panels.
- ❑ Exterior insulation is covered with a protective material to prevent damage. Insulation is protected in attics and mechanical rooms where access is needed.
- ❑ Foundation vents do not interfere with the insulation.
- ❑ Insulation materials in ground contact have a water absorption rate no greater than 0.3 percent.

Fenestration and Doors (§ 5.4.2)

- ❑ U-factors are determined in accordance with NFRC 100. U-factors for skylights shall be determined for a slope of 20° above the horizontal.

Exceptions:

- ❑ U-factors are taken from A.8.1 for skylights.
- ❑ U-factors are taken from A.8.2 other fenestration products.
- ❑ U-factors are taken from A.7 for opaque doors.
- ❑ U-factors are derived from DASMA 105 for garage doors.

- ❑ Solar heat gain coefficient (SHGC) is determined in accordance with NFRC 200.

Exceptions:

- ❑ SHGC is determined by multiplying the shading coefficient (SC) by 0.86. Shading coefficient is determined using a spectral data file determined in accordance with NFRC 300.
- ❑ SHGC for the center of glass is used. SHGC is determined using a spectral data file determined in accordance with NFRC 300.
- ❑ SHGC is taken from § A8.1 for skylights.
- ❑ SHGC is taken from § A8.2 for vertical fenestration.

- ❑ Visible light transmittance is determined in accordance with NFRC 200.

Air Leakage (§ 5.4.3)

- ❑ The *building envelope* is sealed, caulked, gasketed, and/or weather-stripped to minimize air leakage.
- ❑ Air leakage through fenestration and doors is less than 0.4 cfm/ft² (1.0 cfm/ft² for glazed swinging entrance doors and for revolving doors) when tested in accordance with NFRC 400.

Exceptions:

- ❑ Field fabricated fenestration and doors.
- ❑ For garage *doors* tested in accordance with DASMA 105.

- ❑ Cargo doors and loading dock doors are equipped with weatherseals in climates zones 3 through 8.
- ❑ Entrance doors have vestibules.

Exceptions:

- ❑ Climate zone 1 or 2
- ❑ Building is less than four stories.
- ❑ Doors not intended as building entrance.
- ❑ Doors open from dwelling unit(s).
- ❑ Doors open from spaces smaller than 3,000 ft².
- ❑ Building has revolving doors.
- ❑ Doors for vehicular movement or material handling.

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Building Envelope Compliance Documentation

Project Name:			
Contact Person:			Telephone:
Space Category ☐ Nonresidential ☐ Residential ☐ Semiheated	§ 5.5.4.4.1 Exceptions ☐ ☐ Overhangs ☐ Street Level Windows	Window-Wall Ratio Gross Wall Area (ft^2): Window Area (ft^2): Window-Wall Ratio:	Skylight-Roof Ratio Gross Roof Area (ft^2): Skylight Area: Skylight-Roof Ratio

Opaque Surfaces

Description/ Name	Class (Pick one)								Pick one	Pick one	High Reflectance/Emittance Roof	Proposed Insulation R-Value, U-Factor, C-Factor or F-Factor	Criteria Insulation R-Value, U-Factor, C-Factor or F-Factor	Surface Area (ft^2) (optional)
	Roof	Wall			Floor		Slab	Door						
	Insulation Above Deck Metal Building Attic and Other	Mass Metal Building Steel-Framed Wood-Framed / Other	Below-Grade Wall		Mass Steel Joist Wood-Framed / Other		Unheated Heated	Swinging Non-Swinging	R-value Option U-factor Option	Appendix A Defaults Calculations				
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Building Envelope Compliance Documentation

Project Name:	
Contact Person:	Telephone:

Fenestration

Description/ Name	Frame Class (Pick one)									Proposed Fenestration							Criteria	
	Nonmetal (all)	Metal (curtain/storefront)	Metal (entrance door)	Metal (all other	Skylight, Curb, Glass	Skylight, Curb, Plastic	Skylight, No Curb	NFRC Rating	Appendix A Defaults	Area	U-Factor	Solar Heat Gain Coefficient (SHGC)	Overhang	Projection Factor	Overhang Multiplier	Adjusted Solar Heat Gain Coefficient (SHGC)	U-Factor	Solar Heat Gain Coefficient (SHGC)
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6. HVAC Systems

General Information (§ 6.1)

General Design Considerations

HVAC systems are one of the most significant users of energy in the types of buildings covered by the Standard. In typical nonresidential buildings, HVAC energy consumption (exclusive of process loads) is second only to lighting energy consumption. In typical high-rise residential buildings, HVAC and domestic water heating are the two largest energy consumers. HVAC system designers can have a major affect on a building's energy costs and consumption: a poorly designed HVAC system can easily have twice the yearly energy costs of an energy-conserving design.

An efficient system is not merely one that uses efficient equipment. System interactions play a major role in the overall system efficiency. Particularly for systems that serve multiple zones, the efficiency of the air and water distribution systems and how they are controlled can be much more important factors in determining overall HVAC system performance than the efficiency of each piece of equipment.

Overall, the HVAC system performance factor may be defined as the ratio of loads (Q_l) the system must handle (heating, cooling, and water heating) to the energy the system consumes (E):

$$\eta_S = \frac{Q_L}{E} \qquad (6\text{-A})$$

An efficient system will minimize energy use by minimizing system losses, maximizing equipment efficiencies, and utilizing "free" heating and cooling through heat recovery and economizers. A very efficient system could have an overall performance factor greater than one. The requirements of § 6 set minimum standards for the efficiency of HVAC systems. Although compliance with this section should ensure acceptable HVAC system performance, designers may wish to consider designs that exceed these requirements. There are many HVAC system designs and energy conservation measures not covered by the Standard that may improve energy efficiency for a particular application.

Scope (§ 6.1.1)

All mechanical equipment and systems serving a building's heating, cooling, or ventilating needs must meet the requirements of § 6. In the case of alterations to an existing building, HVAC equipment that is a direct replacement of existing equipment must meet the efficiency requirements of the Standard (see § 6.1.1.3). This applies, but is not limited to, air conditioners and condensing units, heat pumps, water chilling packages, packaged terminal and room air conditioners and heat pumps, furnaces, duct furnaces, unit heaters, boilers, and cooling towers. The § 6 efficiency requirements are consistent with those in the National Appliance Energy Conservation Act (NAECA). NAECA is enforced at the equipment point of sale; therefore, the *Standard 90.1* requirements are self-enforcing since NAECA prohibits equipment from being sold that does not meet the requirements.

Inch-Pound and Metric (SI) Units

The Standard is available in two versions. One uses inch-pound (I-P) units, which are commonly used in the United States. The other version uses metric (SI) units, which are used in Canada and most of the rest of the world. Most of the examples and tables in this chapter use inch-pound units; however, where it is convenient, dual units are given in the text. The SI units follow the I-P units in parenthesis. In addition, the following table may be used to convert I-P units to SI units.

	I-P Units		**SI Units**
Length	ft	× 0.3048	= m
	in	× 25.4	= mm
Area	ft²	× 0.0929	= m²
Power	Btu/h	× 0.2928	= W
	Btu/h	× 0.0002928	= kW
	MBtu/h	× 292.8104	= kW
	ton	× 3.513725	= kW
Temperature	(ºF – 32)	× 0.5555	= ºC
Pressure	psi	× 6894.757	= Pa
	in. w. c.	× 249.10	= Pa
Airflow	cfm	× 0.4719	= l/s
	cfm/ft²	× 5.0776	= l/s·m²
Liquid Flow	gpm	× 0.0757682	= l/s
Volume	gal	× 3.785412	= l
R-factor	h·ft²·ºF/Btu	× 0.1762	= m²·ºC/W
Conductivity	Btu-in./h·ft²·ºF	× 0.1441	= W/mº·C
Efficiency	Btu/h·W	× 0.2928104	= η
	kW/ton	× 3 .517	= 1/η

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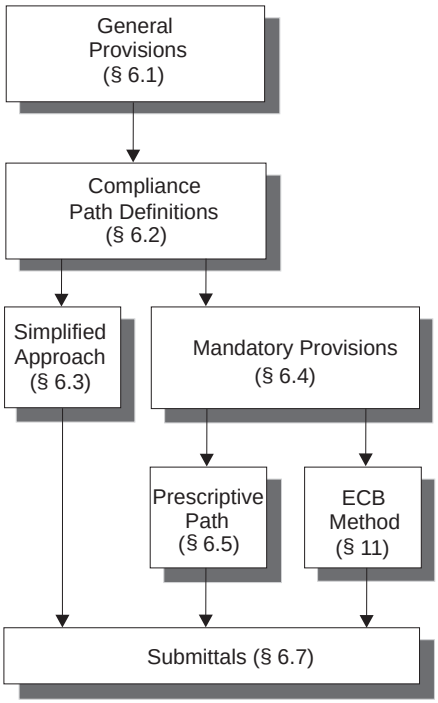
General Provisions (§ 6.1)
Compliance Path Definitions (§ 6.2)
Simplified Approach (§ 6.3)
Mandatory Provisions (§ 6.4)
Prescriptive Path (§ 6.5)
ECB Method (§ 11)
Submittals (§ 6.7)

Figure 6-A—Compliance Options

There are a number of important instances when the Standard does not apply to replacement HVAC equipment. In particular, the Standard does not apply (see exceptions to § 6.1.1.3):

- When equipment is repaired but not replaced. As long as parts within the unit are being replaced and not the unit as a whole, the Standard does not apply. However, the modifications may not increase energy use. For instance, if a condenser coil is replaced, the new coil must have the same heat transfer performance (tube and fin spacing, fin type) as the coil being replaced.
- When the replacement of existing equipment with complying equipment requires extensive revisions to other systems, equipment, or elements of the building and where the replacement equipment is a like-for-like replacement. For example, if extensive modifications to a building or heating distribution system are required to accommodate replacement of an existing boiler with a new boiler that complies with the Standard, compliance is not required.
- When the refrigerant in existing equipment is changed. This will often reduce efficiency but may be required in order to reduce the ozone-depletion potential of the equipment or to meet other regulatory requirements.
- When existing equipment is relocated. For instance, the Standard does not apply when an existing hydronic heat pump is moved to another location within the building.

Compliance Methods (§ 6.2)

There are three approaches to compliance with the Standard for HVAC systems.

Simplified Approach

This approach is applicable to relatively simple systems in small buildings. The approach was created to save time and reduce complexity for designers of such systems, which represent a large majority of the HVAC systems being installed in the U.S. today. Systems complying using this approach only have to meet § 6.3; this is essentially a subset of the mandatory and prescriptive requirements of § 6 and includes only those requirements that are typically applicable to the HVAC systems found in small buildings.

Prescriptive Path

The prescriptive compliance path may be used for any HVAC system, but it is primarily used for the complex systems in larger buildings where the Simplified Approach is not applicable, such as variable air volume systems and central hydronic heating and cooling plants. Systems complying using this approach have to meet § 6.4 (Mandatory Provisions) and § 6.5 (Prescriptive Path).

Energy Cost Budget (ECB) Method

The ECB Method is designed for building systems that are unable to meet certain prescriptive requirements. It allows trade-offs between various building systems and components. Systems complying using the ECB approach must meet § 6.4 (Mandatory Provisions) and § 11 (Energy Cost Budget Method). This approach is addressed in Chapter 11 of this Manual.

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Simplified Approach Option (§ 6.3)

Scope (§ 6.3.1)

The Simplified Approach option for HVAC systems is designed to reduce the effort required to show compliance for HVAC systems serving small buildings. Small buildings (those less than 25,000 ft²) represent more than 80% of new construction building starts in the U.S. and they generally are served by simple, single-zone HVAC systems. Many of the requirements in § 6 do not apply to these simple systems; rather than require designers of these systems to search through the entire section for requirements that do apply, these requirements are grouped into one section, § 6.3. This approach is intended to be entirely consistent with the Prescriptive Path so that a system complying by either approach is subject to the same requirements.

The Simplified Approach can only be used for the following buildings and system types:

- The building served by the system must be two stories or less in height.
- The building served by the system must be less than 25,000 ft² in gross floor area.
- The HVAC system must serve a single zone. Systems with any level of subzoning, i.e., systems with any more than one thermostatic control, cannot use this approach for showing compliance.
- The system either must not have a mechanical cooling system or, if cooling is provided, it must be from a unitary packaged or split-system air conditioner that is either air-cooled or evaporatively cooled.

Criteria (§ 6.3.2)

If the basic qualifications are met and the designer chooses to demonstrate compliance with the Standard by using the Simplified Approach, the HVAC system must meet the following requirements.

Cooling Efficiency (§ 6.3.2b)

Cooling (if provided) efficiency must meet the requirements shown in Table 6.8.1A (air conditioners), Table 6.8.1B (heat pumps), or Table 6.8.1D (packaged terminal and room air conditioners and heat pumps) for the applicable equipment category. See Mandatory Provisions in this chapter for further information on equipment efficiency ratings.

Economizers (§ 6.3.2b)

If the system has mechanical cooling with a capacity that exceeds the limit shown in Table 6.5.1, the system must have an outdoor air economizer. Where the cooling efficiency meets or exceeds the efficiency requirement in Table 6.3.2, no economizer is required. High limit controls (the controls that shut off the economizer in warm weather) must meet the requirements of Tables 6.5.1.1.3A and 6.5.1.1.3B. The system must have either barometric or powered relief sized to prevent overpressurization of the building when the economizer is on and outdoor air rates are high. Outdoor air dampers for economizer use must be provided with blade and jamb seals (i.e., they must be "low leakage" style dampers).

Example 6-A—Simplified Approach, Building Area Restriction

Q

A strip shopping mall building contains a series of small stores. Each store is approximately 5,000 ft².. The stores are attached to each other and separated only by common demising walls. The overall contiguous area of the mall is 80,000 ft². Can the Simplified Approach be used to show compliance for a rooftop packaged air-conditioning unit serving one of the small tenants?

A

Yes. The term "building" is defined in § 3 as "a structure wholly or partially enclosed within exterior walls, or within exterior and party walls…." The party walls between tenants in the mall define each tenant to be a separate *building* for the purposes of compliance with this Standard. Hence, the Simplified Approach may be used for each tenant that occupies less than 25,000 ft² in gross area (assuming the other restrictions to this approach are met).

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Heating (§ 6.3.2d)
For systems with heating capability, the following heating options meet the Standard's requirements:

- Unitary heat pump that meets the efficiency requirements shown in Table 6.8.1B (heat pumps) or Table 6.8.1D (packaged terminal and room air conditioners and heat pumps);
- Fuel-fired furnace that meets the efficiency requirements shown in Table 6.8.1E (furnaces, duct furnaces and unit heaters);
- Electric resistance heater; or
- Hot water or steam baseboard convectors or radiators connected to a boiler that meets the efficiency requirements shown in Table 6.8.1F.

Outdoor Air Heat Recovery (§ 6.3.2e)
If the outdoor air quantity supplied by the system is 3,000 cfm or greater and it comprises 70% or more of the supply air quantity at minimum outdoor air design conditions, an energy recovery ventilation system must be provided in accordance with the requirements of § 6.5.6.

Thermostat (§ 6.3.2f)
The system must be controlled by a manual changeover or dual setpoint thermostat. Almost all thermostats offered as standard options from unitary equipment manufacturers comply with this requirement.

Heat Pump Auxiliary Heat Control (§ 6.3.2g)
If heat is provided by a heat pump that is equipped with auxiliary electric resistance heaters installed within the heat pump air-handling unit, controls must be provided that prevent supplemental heater operation when the heating load can be met by the heat pump alone during both steady-state operation and setback recovery. Supplemental heater operation is permitted with heat pump operation during outdoor coil defrost cycles. Two common control options that meet this requirement include:

- A digital or electronic thermostat designed for heat pump use that energizes auxiliary heat only when the heat pump has insufficient capacity to maintain setpoint or to warm up the space at a sufficient rate; and
- A multistage space thermostat and an outdoor air thermostat wired to energize auxiliary heat only on the last space thermostat stage and when outdoor air temperature is less than 40°F (4°C).

Heat pumps whose minimum efficiency is regulated by NAECA and whose HSPF rating both meets the requirements shown in Table 6.8.1B and includes all usage of internal electric resistance heating are exempted from these control requirements.

Reheat for Humidity Control (§ 6.3.2h)
The system controls must not permit reheating, recooling, or any other form of simultaneous heating and cooling for humidity control. If, in a humid climate, reheat/recool is desired for humidity control, the Prescriptive Path must be used to demonstrate compliance. (This path allows reheat for humidity control, with several limitations. See the discussion on Dehumidification Systems (§ 6.5.2.3) in this chapter.)

Off-Hour Shutoff and Setback (§ 6.3.2i)
Systems serving spaces other than hotel/motel guest rooms, and other than those requiring continuous operation, that have both a cooling or heating capacity greater than 15,000 Btu/h (4.4 kW) *and* a supply fan motor power greater than 3/4 hp (0.5 kW) must be provided with a time switch/controller with the following capabilities:

- Can start and stop the system under different schedules for seven different day-types per week;
- Is capable of retaining programming and time setting during a loss of power for a period of at least 10 hours;
- Includes an accessible manual override that allows temporary operation of the system for up to 2 hours;
- Is capable of temperature setback down to 55°F during off hours; and
- Is capable of temperature setup to 90°F during off hours.

A true seven-day electronic thermostat (typically an option from the unitary equipment manufacturer) will meet these requirements. However, weekday/weekend (5-2) and weekday/Saturday/Sunday (5-1-1) thermostats, typically intended for residential applications, do *not* comply with this requirement.

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Piping Insulation (§ 6.3.2j)
Except for piping within manufacturers' units, HVAC piping must be insulated in accordance with Table 6.8.3. Insulation exposed to weather must be suitable for outdoor service (e.g., protected by aluminum, sheet metal, painted canvas or plastic cover). Cellular foam insulation must also be protected as described above, or painted with a coating that is water retardant and provides shielding from solar radiation. The insulation requirements for the most common small system applications are shown in Table 6-A.

Ductwork Insulation (§ 6.3.2k)
Ductwork and plenums must be insulated in accordance with Tables 6.8.2A and 6.8.2B and sealed in accordance with Tables 6.4.4.2A and 6.4.4.2B. See the discussion on HVAC System Insulation (§ 6.4.4.1) in this chapter for more details.

Air Balancing (§ 6.3.2l)
Construction documents must require that all HVAC systems with field-installed ductwork be air balanced in accordance with industry-accepted procedures. Industry-accepted test and balance standards include:

- ANSI/ASHRAE *Standard 111*.
- National Environmental Balancing Bureau Procedural Standards.
- Associated Air Balance Council National Standards.

See Appendix E to the Standard for details.

Simultaneous Heating and Cooling (§ 6.3.2m)
Where separate heating and cooling equipment serve the same temperature zone, thermostats must be interlocked to prevent simultaneous heating and cooling. Situations where this requirement may apply include two or more systems serving a single space, such as a baseboard heating system and an overhead cooling system. If each of these units has its own thermostat, the controls must be interlocked to prevent the heating and cooling from operating simultaneously.

Another example is a theater or large meeting room served by two or more units. The thermostats for each unit will generally prevent the heating and cooling within the unit from simultaneously operating, but when two units serve the same room, it's possible for one to be heating and the other to be cooling unless the thermostats are properly interlocked.

Table 6-A—Piping Insulation Requirements for Common Small System Applications

Application	Minimum thickness of cellular foam or fiberglass
Refrigerant suction line (split system air conditioner) or hot gas (split system heat pump), up through 1¼ in. NPS (1⅜ in. OD copper)	½ in.
Refrigerant liquid lines	None
Hydronic heating hot water piping, 141°F to 200°F < 4 in. NPS	1 in.

For applications not shown, see Table 6.8.3 and discussion on Piping Insulation (§ 6.4.4.1.3) in this chapter. For other insulation types, see discussion on Piping Insulation (§ 6.4.4.1.3).

Example 6-B—Simplified Approach, Single-Zone Restriction

Q

A gas/electric packaged air-conditioning unit serves a small office building. The unit is a standard single-zone unit but it serves multiple zones through a variable air volume changeover control system (often called "VVT," a trademark of the original control system manufacturer). Can this system show compliance using the Simplified Approach?

A

No. The Simplified Approach may only be used for units serving a single HVAC zone, defined in § 3 as "a space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g., temperature) can be maintained throughout using a single thermostatic control (e.g., thermostat or temperature sensor to a separate controller)."

While the air-conditioning unit in this example is a single-zone unit, the "VVT" control system expands the number of zones beyond one, making it ineligible for the Simplified Approach.

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Shutoff Dampers (§ 6.3.2n)
Exhaust fans with a design capacity of over 300 cfm that do not operate continuously must be equipped with gravity or motorized dampers that will automatically shut when the systems are not in use. Backdraft shutters or motorized dampers are generally standard options on most exhaust fans.

Optimum Start (§ 6.3.2o)
Systems with a design supply air capacity greater than 10,000 cfm must have "optimum start" controls. Optimum start controls are defined in § 3 as "controls that are designed to automatically adjust the start time of an HVAC system each day with the intention of bringing the space to desired occupied temperature levels immediately before scheduled occupancy." Optimum start routines are usually standard for digital control and energy management systems. Start time is computed from the current outdoor air temperature, space temperature, and a mass/capacity factor that describes how quickly the system can warm up or cool down the space. This factor is often self-tuned by the controller based on historical performance.

For installations using electric controls, so-called "intelligent controls" also comply with the Standard. This control logic, which is an option on some electronic thermostats, adjusts start time based on the difference between current space temperature and occupied setpoint. Even though the logic ignores outdoor air temperature and the mass/capacity factor is not usually adjustable, this control logic meets the definition of "optimum start" and thus complies with this section.

Example 6-C—Simplified Approach, Example Application

Q

A 7.5-ton rooftop gas/electric air-conditioning unit is planned for a new 2,500 ft², single-story retail store in Las Vegas, Nevada (climate zone 3B, T_H = 27°F, T_{DB} = 106°F, T_{WB} = 66°F, hours between 55°F and 69°F = 719; see Appendix D for climate data). The unit requires 750 cfm of outdoor air and supplies 2600 cfm of total supply air with a total load of 84,000 Btu/h. Supply and return air ducts are located in a ceiling attic between a suspended ceiling and an insulated roof. A small 75 cfm exhaust fan serves the employees' toilet room.

What is required for the system to comply with the Standard using the Simplified Approach?

A

There is not just one way to comply with the Simplified Approach, but the following is a typical example of how this system could meet the requirements.

Cooling Efficiency: According to Table 6.8.1A, the minimum ARI-rated efficiency is 10.3 EER (energy efficiency ratio) at full load. However, since this unit has gas heat, the EER can be reduced by 0.2. (This allowance is due to the additional pressure drop from the furnace, which increases fan energy requirements.) Hence, the selected air-conditioning unit must have an EER of 10.1 or greater

Economizers: An economizer is required for this cooling system since its capacity (84,000 Btu/h) exceeds the value in Table 6.5.1 for this climate (65,000 Btu/h).

In climate zones 2–4, as an alternative to the economizer requirement, a high efficiency air-conditioning unit can be selected using Table 6.3.2. In this example, the high efficiency requirement for climate zone 3 is 12.0. So instead of using an economizer, a unit with an EER of 11.8 (12.0 less 0.2 because of the gas heat) could be installed. If an economizer is specified for this unit, a high limit control must also be specified. According to Tables 6.5.1.1.3A and 6.5.1.1.3B, the allowable controls include:

- Fixed Dry-Bulb (i.e., an outdoor air thermostat), set to shutoff the economizer above 75°F outdoor air temperature;
- Differential Dry-Bulb (a temperature sensor in the return airstream and one in the outdoor airstream) that will shutoff the economizer when the outdoor air temperature exceeds the return air temperature;
- Electronic Enthalpy (a solid state device that uses a combination of humidity and dry-bulb temperature in its switching algorithm) set to setpoint "A"; or
- Differential Enthalpy (an enthalpy sensor in the return airstream and one in the outdoor airstream) that will shutoff the economizer when the outdoor air enthalpy exceeds the return air enthalpy.
- Fixed Dew Point and Dry-Bulb (outdoor air temperature sensors) set to shutoff the economizer when outdoor air dry-bulb is above 75°F or outdoor air dew point is above 55°F.

[continued on next page]

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Mandatory Provisions (§ 6.4)

The Mandatory Provisions apply to all systems complying by the Prescriptive Path or the Energy Cost Budget Method. These requirements do not apply to systems complying by the Simplified Approach.

Mechanical Equipment Efficiency (§ 6.4.1)

General

HVAC equipment efficiency requirements in the original version of Standard 90 published in 1975 addressed equipment full-load efficiency as measured at standard rating conditions, representative of typical peak design conditions. In the 1989 version, minimum part-load efficiency levels were added for most equipment types, recognizing that most equipment operates at part load most or all of the time. However, the part-load requirements were not stringent due to the lack of actual product part-load performance data available at the time. Standard 90.1-2007 continues to recognize both full- and part-load efficiency of some HVAC equipment, but the level of stringency has been increased.

Efficiency Requirements

Equipment must meet or exceed the energy efficiencies shown in Tables 6.8.1A through 6.8.1J of the Standard when measured in accordance with the rating standards as specified in the tables.

Equipment efficiency requirements apply to all equipment, regardless of compliance path (Simplified Approach, Prescriptive Path, or Energy Cost Budget Method). Therefore, equipment must meet the requirements of this section even if compliance could be shown with the Energy Cost Budget Method using equipment with lower efficiencies.

In most cases, the efficiency of

Example 6-C—Simplified Approach, Example Application *[continued]*

A Fixed Enthalpy limit switch is not allowed in this climate.

Of the five allowed controls, the least expensive and most reliable option is the fixed dry-bulb thermostat. The differential and electronic enthalpy controls, while allowed, are not the best option in this dry climate due to their higher cost and marginal energy savings compared to dry-bulb high limit controls.

Another requirement for systems with economizers is that they must have either barometric or powered relief sized to prevent overpressurization of the building when the economizer is on. With most larger rooftop units, both are standard options. Where they are not options on the air-conditioning units themselves, separate relief hoods or fans must be provided. One final requirement for economizers: Outdoor air dampers must be provided with blade and jamb seals. Generally, this requires that "low leakage" (as opposed to "standard") dampers must be specified.

Heating: The gas furnace must meet the efficiency requirements shown in Table 6.8.1E. For this example, the requirement is in the row labeled "Warm Air Furnace, Gas-Fired," with capacity less than 225,000 Btu/h. In this case (see footnote d in Table 6.8.1E), the furnace can meet either of two requirements: 78% AFUE (annual fuel utilization efficiency) or 80% E_t (thermal efficiency at full load). It's more likely that the furnace will meet the latter requirement, since AFUE is unlikely to have been measured for this product, which is not covered by the National Appliance Energy Conservation Act (NAECA).

Thermostat and Off-Hour Controls: A true seven-day electronic thermostat can be specified to meet several requirements, including those for dual setpoints, off-hour shutoff, setback and setup.

Ductwork Insulation: In this climate (zone 3B), according to Table 6.8.2B for ducts located in "Unvented Attic w/ Roof Insulation," the supply air duct insulation must have an R-value of R-3.5. This can be met with 1½ in. fiberglass duct wrap or 1 in. of fiberglass or closed-cell foam duct liner. (See Table 6-D under Ductwork Insulation for a list of standard duct insulating materials that meet this R-value requirement.)

Ductwork Sealing: The supply air and return air ducts are low pressure and located in an unconditioned space; therefore, they must be sealed to Seal Class B. See the discussion of HVAC System Insulation (§ 6.4.4) in this chapter for more details.

Air Balancing: A note must be added to the design drawings or the specifications calling for the system to be balanced according to ASHRAE 111, NEBB, AABC, or some other industry-recognized standard.

Shutoff Dampers: Since the toilet exhaust fan is less than 300 cfm, the Standard does not require it to be fitted with a backdraft damper.

Optimum Start, Humidity Control, and all other sections not addressed in this example do not apply to this example system.

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products will be established by certification programs from industry associations such as GAMA, ARI, AHAM, CTI, etc. Where such certification programs exist but a manufacturer chooses not to participate, equipment performance must be verified by an independent laboratory test. Where there is no industry certification program, equipment efficiencies must be supported by data furnished by the manufacturer. Field tests of performance are not required.

Notes applying to Tables 6.8.1A through 6.8.1J:

- Some of the equipment efficiency requirements are covered by the National Appliance Energy Conservation Act (NAECA). The NAECA requirements are listed in the table for the convenience of the user but they were not established by ASHRAE.
- Some of the equipment efficiency requirements are covered by the Federal Energy Policy Act of 1992 (EPAct) and addenda, which means the equipment shall comply with U.S. Department of Energy certification requirements. Efficiency requirements for EPAct-covered products were established by ASHRAE, but only the full-load efficiency requirements were referenced in the legislation. Since EPAct is a preemptive law, meaning no state or local legislation can be more or less stringent, the part-load requirements for EPAct-covered products were deleted from the Standard.
- Single-package vertical air conditioners (SPVAC) and heat pumps (SPVHP) are now covered by EPAct as commercial products. These units consist of a separate encased or un-encased combination of cooling and optional heating components, factory assembled as a single package, and intended for exterior mounting at an outside wall. The performance of these units are rated according to ARI 390.
- Cooling towers shall be tested using the test procedures in CTI ATC-105 and CTI STD-201.
- Tables 6.8.1A and 6.8.1B now cover through-the-wall air-cooled air conditioners and heat pumps with capacity less than 30,000 Btu/h and for small-duct high-velocity air-cooled air conditioners and heat pumps with capacity less than 65,000 Btu/h. The minimum efficiency requirements depend on whether the equipment's date of manufacture is before 1/23/2006; between 1/23/2006 and 1/23/2010; or after 1/23/2010.
- As of 1/23/2006, air-cooled unitary air conditioners and heat pumps with cooling capacity less than 65,000 Btu/h have to meet cooling SEER 12. (Note: as indicated in Footnote c to Table 6.8.1B, federal regulations specify a SEER 13.0 minimum for single-phase equipment.) The heat pump also has to meet heating HSPF 7.4.
- Equipment not listed in the tables has no minimum performance requirements. These products may be used regardless of their efficiency. (Examples include pumps and electric resistance heaters.)
- Most equipment has more than one efficiency requirement, such as one at full-load and one at part-load operation or at non-design conditions. To comply, equipment must satisfy all stated requirements, unless otherwise exempted by footnotes in the table.
- Equipment that provides both space and water heating must comply with the efficiency requirements of the primary function of that particular appliance. For example, a space heating boiler that also provides service hot water must comply with the boiler efficiency requirements in Table 6.8.1F. A water heater that also provides space heating must comply with the efficiency requirements in Table 7.8.
- Where components from different manufacturers are used to field-build a product listed in the tables, the system designer must specify the performance of each component so that their combined efficiency meets the minimum equipment efficiency requirements in the tables. The most common example of this is a split system heat pump or air conditioner built using an indoor coil and air-handler from one manufacturer and an outdoor condensing unit or heat pump unit from another manufacturer. This is allowed, but the designer (rather than the component manufacturers) must ensure that the combined performance meets the requirements of the Standard.

Additional Requirements for Furnaces and boilers.

- In addition to meeting the efficiency requirements listed in the tables, all forced air furnaces (including fuel-fired and electric resistance) with input ratings ≥ 225,000 Btu/h (65 kW) must have the following features:
- Gas-fired and oil-fired furnaces must have an intermittent ignition or interrupted device (IID).
- Gas-fired and oil-fired furnaces must have either power venting or a flue damper. A vent damper is also acceptable for furnaces where combustion air is drawn from the conditioned space.
- Gas-fired and oil-fired furnaces must have jacket losses not exceeding 0.75% of the input rating.
- Furnaces that are other than gas- or oil-fired, such as electric resistance forced air furnaces, that are not located within the conditioned space must have jacket losses not exceeding 0.75% of the input rating.
- Boilers requirements are stated in terms of average fuel utilization efficiency

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(AFUE), thermal efficiency (E_t) and/or combustion efficiency (E_c).

Special Requirements for Centrifugal Chillers
The centrifugal chiller efficiency requirements in Table 6.8.1C apply only to chillers designed for standard ARI rating conditions (evaporator: 2.4 gpm/ton, 44°F leaving water temperature; condenser: 3.0 gpm/ton, 85°F entering water temperature). It is very unlikely that a chiller will be selected for these precise conditions. For those chillers selected for non-standard conditions, the requirements of Tables 6.8.1H through M apply. These tables list chiller efficiency as a function of leaving chilled water temperature, entering condenser water temperature, and condenser water flow rate per unit capacity; Tables 6.8.1H through J are used for the full-load efficiency (COP) and Tables 6.8.1H through M are used for the part-load efficiency (IPLV/NPLV).

The efficiency requirements apply only to chillers with full-load design conditions in the following ranges:

- Leaving Chiller Water Temperature: 40°F to 48°F
- Entering Condenser Water Temperature: 75°F to 85°F
- Condensing Water Temperature Rise: 5°F to 15°F

Chillers whose design operating conditions fall outside of these ranges or applications utilizing fluids or solutions with secondary coolants (e.g., glycol solutions or brines) with a freeze point of 27°F or less for freeze protection are not covered by the Standard and may be used regardless of their efficiency. Typical examples are: chillers designed for ice storage systems, or chillers using glycol for freeze protection.

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Example 6-D—Multiple Requirements, Unitary Heat Pump

Q

What are the efficiency requirements for a 25-ton unitary air-source heat pump?

A

Table 6.8.1B contains the requirements for unitary heat pumps both in the cooling and heating modes. For cooling, the unit falls into the cooling capacity range "≥240,000 Btu/h" and must meet both the full-load EER and the part-load IPLV requirements of 9.0 and 9.2, respectively. For heating, the unit falls into the 135,000 Btu/h cooling capacity range (note this is still the cooling capacity here, not the heating capacity) and must meet a heating COP requirements of 3.1.

Example 6-E—Requirements, Single-Package Vertical Heat Pump

Q

What are the efficiency requirements for a 3-ton single-package vertical heat pump?

A

All sizes of single-package vertical heat pump must have a minimum cooling EER of 8.6 and a minimum heating COP of 2.7 listed in Table 6.8.1D.

Example 6-F—Performance Requirements, Equipment That Was Stored

Q

A 5-ton SEER 10 and HSPF 7.0 single package air-cooled heat pump manufactured in 2003 has been in storage and is to be installed in a building in 2007. Does the heat pump comply with the Standard 90.1-2007?

A

Yes. The date of manufacture (2003) determines that the heat pump has to meet cooling SEER 9.7 and heating HSPF 6.6, as shown in Table 6.8.1B. If the heat pump is manufactured after 1/23/2006, it would not comply, because the Standard requires minimum SEER 12 and HSPF 7.4.

Example 6-G—Date of Manufacture, Equipment

Q

How do I find the date of manufacture for a piece of equipment?

A

First, check the equipment nameplate. In some cases, you may have to call the supplier or manufacturer.

Example 6-H—Chiller Design for Dual Duty

Q

A chiller that is part of an ice-storage system is designed both to produce brine at 25°F to make ice during off-peak periods and to produce normal chilled water temperatures (40°F to 45°F) during on-peak and partial-peak periods. Since one of the design conditions is for chilled water temperatures that are within the range shown in Tables 6.8.1H through M, must the chiller meet the efficiency requirements listed in the table?

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A

No. Chillers that are specifically designed to operate at conditions outside the temperature ranges listed in Table 6.8.1H through M are exempt because: (1) they are not able to operate under these conditions, or (2) they operate inefficiently under these conditions because they are designed to operate under other, more extreme design conditions. In this example, the chiller must be able to handle the high lift required to produce low temperature brine for making ice. This may make the chiller inefficient when producing chilled water within standard temperature ranges.

Example 6-I— Centrifugal Chiller Design for Non-Standard Conditions

Q

What are the efficiency requirements for a 250-ton centrifugal chiller operating at the following design conditions:

- 45°F leaving chilled water temperature,
- 80°F entering condenser water temperature, and
- 3.0 gpm/ton condenser water flow?

A

Since this centrifugal chiller operates at temperatures different from the ARI 550/590 rating condition (44°F chilled water supply and 85°F condenser water supply), the full- and part-load efficiencies for this chiller come from Tables 6.8.1 H through M. For a 250-ton chiller, the full load requirement comes from Table 6.8.1I. For the specified conditions the required COP is 6.05 (as opposed to the standard rating of 5.55 from table 6.8.1 C). The NPLV comes from Table 6.8.1I; the required NPLV is 6.46 (as opposed to the standard rating of 5.90 from table 6.8.1 C).

Example 6-J—Part-Load Performance Requirements, Air Conditioner with a Single Compressor

Q

A 7.5-ton rooftop air conditioner has a single compressor with no unloading capability. Must this unit meet the IPLV requirement of Table 6.8.1A?

A

No. Footnote b to the table states: "IPLVs are only applicable to equipment with capacity modulation." IPLVs are determined by measuring performance at steady-state part-load conditions. If the equipment cannot operate at that condition without cycling, its steady-state performance cannot be measured. Thus, for a single-speed compressor with no cylinder unloading, IPLV requirements do not apply.

Example 6-K—High Pressure Boiler

Q

A gas-fired boiler is designed to provide 125 psig steam. What efficiency requirements must be met?

A

None. The term "boiler" is defined in § 3 to be "low pressure," which is commonly understood in the industry to refer to steam at 15 psig or lower and hot water at 160 psig or lower. Therefore, boilers designed for higher pressures are not covered by the Standard and may be installed regardless of their efficiency.

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Energy Efficiency Descriptors and Overall System Energy Usage

The descriptors used to characterize the efficiency of the various equipment types in Tables 6.8.1A to M apply only to the efficiency of the equipment itself and not any other equipment that may be required to complete the system. When determining which type of system to select, it is usually not possible to compare the efficiency of different equipment types simply by looking at the values in the table. For instance:

- The efficiency ratings for water-cooled equipment cannot be directly compared to those for air-cooled equipment. Water-cooled equipment ratings do not include the energy used by condenser water pumps and cooling tower fans while air-cooled package ratings include condenser fan energy.
- The ratings for condensing units cannot be directly compared to ratings for packaged or split system air conditioners. Condensing unit ratings do not include the energy used by indoor air-handling fans.
- Efficiency ratings for different types of furnaces account only for gas usage but do not include the energy used by combustion air fans and indoor air-handler fans that vary from one furnace to another.
- The efficiency of a chilled-water system cannot be compared to a unitary direct-expansion system using standard ratings. Chilled-water system efficiency does not include the energy used by chilled-water pumps and air-handler fans.
- Equipment efficiencies listed in the tables are for standard rating conditions. Actual efficiency will vary depending on how the equipment is applied and how it is controlled.
- Even a direct comparison of seemingly like energy descriptors may be misleading because of differences in rating conditions or definitions. For instance, the cooling efficiency of groundwater-source heat pumps may appear higher than standard water-source heat pumps, but this is mostly due to the differing rating conditions; the groundwater-source heat pumps are rated at 70°F entering water temperature compared to 85°F for water-source heat pumps.

A fair comparison between different types of equipment, such as water versus air-cooled equipment, requires knowledge of the auxiliary equipment needed for a complete system and the energy they use both at full and part load. Often an energy analysis of the detail required by § 11 is the only way to make an accurate comparison.

Load Calculations (§ 6.4.2)

The designer must make heating and cooling load calculations before selecting or sizing HVAC equipment. This requirement helps to ensure that equipment is neither oversized nor undersized for the intended application. Oversized equipment not only increases first costs but also usually operates less efficiently than properly sized equipment. It can also result in reduced comfort control due to, for example, lack of humidity control in cooling systems and fluctuating temperatures from short-cycling.

Undersizing will obviously result in poor temperature control in extreme weather but can also increase energy usage at other times. For example, an undersized heating system may have to be operated 24 hours per day because it has insufficient capacity to warm up the building each morning in a timely manner.

Accurate calculation of expected heating and cooling loads begins with a reliable calculation methodology. The Standard requires that calculation procedures be in accordance with "engineering standards and handbooks acceptable to the adopting authority (for example, ASHRAE *Handbook—Fundamentals*)." This wording allows the use of many other time-proven load calculation programs that may not precisely follow ASHRAE procedures, such as those developed by some of the major equipment manufacturers and other professional groups.

There is no universal agreement among engineers on a single load calculation procedure, and the available procedures produce results that vary by 30% or more. This is because the thermodynamic performance of buildings and HVAC systems is so complex that calculation methods and computer software have simplifying assumptions embedded within them to make them practical to use. Depending on the application, these simplifications can result in inaccuracies and errors. The designer should be aware of the limitations of the calculation tool used and apply reality checks to the results, based on past real life experience, to avoid sizing errors.

While load calculations are required, there is no requirement that actual equipment sizes correspond to the calculated loads. In past versions of the Standard, sizing equipment consistent with load calculations was required for compliance using the Prescriptive Path. However, it proved very difficult to enforce this requirement given the wide variation in load calculation methods and differing assumptions regarding internal loads and other parameters. Further, there are cases where oversizing actually improves energy efficiency (e.g., oversizing ducts, piping, cooling towers, etc.) so it is difficult to regulate oversizing without introducing many exceptions and associated complexity.

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So why does the Standard require load calculations when there is no corresponding requirement to use the calculations for equipment sizing? The reason is in part because old rules-of-thumb used to size systems may no longer be applicable. Building envelopes continue to improve. Spectrally selective fenestration reduces solar gain and the cooling load while maintaining good daylight transmission. Low-emissivity coatings and gas-fill for fenestration, and opaque sections with greater insulation levels and fewer thermal bridges, can reduce heating loads and sometimes eliminate the need for separate perimeter heating systems. Lighting loads continue to go down, and in many cases office equipment loads are lower due to more efficient PCs.

Once load calculations are done, using them for selecting equipment is at least partly self-regulating due to normal market incentives. For instance, if a load calculation indicates that a 5-ton air-conditioning unit will handle an application, it is not likely that the designer or contractor will deliberately select a 10-ton unit because of its added first costs. On the other hand, if the equipment had been selected using only rules-of-thumb without calculations, the larger unit may have been chosen. The expectation is that most designers will properly size equipment if load calculations are made.

The Standard does not describe how the load calculations requirement is to be enforced because that is up to the authority having jurisdiction. Since enforcement agencies need only see that calculations have been done, they should request only to see a summary of load calculations such as a single-page computer printout for the building or system and should not require that the entire detailed calculation package be submitted.

Example 6-L—Process Conditioning

Q

An air-cooled split system computer-room air conditioner serves a large telephone switching equipment room. What efficiency requirements must be met?

A

None. This example presents two issues: the requirements for unlisted equipment and the exemption for equipment that serves process loads.

Air conditioners in telephone switching equipment rooms are specialty equipment not listed in Tables 6.8.1A to M and therefore have no minimum efficiency requirements.

The present scope of the Standard does not include "equipment and portions of building systems that use energy primarily to provide for industrial, manufacturing, or commercial processes." Since the telephone switching equipment room is conditioned to provide the right environment for the telephone switchgear, it is not covered by the Standard, so equipment and systems that serve such process equipment rooms in general need not comply with any requirements of the Standard.

However, those parts of the system (e.g., chiller plant) that serve nonprocess areas covered by the Standard must comply with applicable sections including equipment efficiency requirements.

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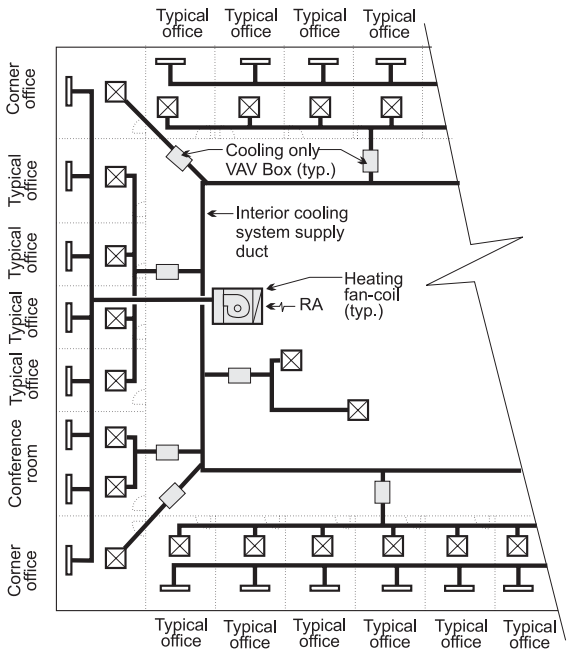

Figure 6-B—Independent Cooling and Heating Systems

Controls (§ 6.4.3)

Zone Thermostatic Controls (§ 6.4.3.1.1)

An HVAC thermostatic control zone is defined as a space or group of spaces whose load characteristics are sufficiently similar that the desired space conditions can be maintained throughout with a single controlling device. The Standard requires that the supply of heating and cooling to *each* such zone be individually controlled by a thermostatic controller that senses the temperature within the zone.

To meet this requirement, spaces must be grouped into proper control zones. For instance, spaces with exterior wall and glass exposures cannot be zoned with interior spaces. Similarly, spaces with windows facing one direction should not be zoned with windows facing another orientation unless the spaces are sufficiently open to one another that air may mix well between them to maintain uniform temperatures.

Zoning in this manner does not apply to residential dwelling units. The Standard specifically allows an individual dwelling unit to be served as if it were a single zone. In other words, a single thermostat may be used to control the supply of heating and cooling to all rooms within the dwelling unit even if they face different exposures or operate with different occupancy schedules.

DDC or standard pneumatic controllers may be used for either zone thermostatic or supply loop control.

Independent Perimeter Systems (Exception to § 6.2.3.1)

This exception applies to perimeter zones that are served by two independent HVAC systems. One of the two systems, called the perimeter system, is designed to offset only "skin loads," those loads that result from energy transfer through the building envelope. Typically, the perimeter system is designed for heating only. Interior loads, such as those from lights and people, are controlled by a second system called the interior system. This system may also be designed to handle skin cooling loads if the perimeter system is heating-only.

Figure 6-B shows an example of this HVAC system design. In this example, the perimeter system consists of a heating-only fan coil, one for each building exposure. The interior system consists of a cooling-only VAV system serving the entire floor, including all exposures as well as interior zones.

This design does not strictly meet the thermostatic control requirements since the perimeter system supplies heating to several zones at once. In Figure 6-B, the heating fan coil shown serves four zones of the VAV system. Therefore, heating energy from the fan coil is not controlled by individual thermostats in each zone as required, and there is the possibility, or even probability, that the interior system and the perimeter system will fight each other, with the perimeter system overheating some spaces and the interior system overcooling them to compensate. This obviously wastes energy.

This exception allows the design shown in Figure 6-B only if the potential for fighting between the interior and perimeter systems is mitigated as follows:

- The perimeter system has at least one zone for each major exposure, defined as an exterior wall that faces 50 contiguous feet or more in one direction. Exterior

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walls are considered to have different orientations if the directions they face differ by more than 45 degrees. For example, in Figure 6-C, a zone must be provided for each of the exposures that exceed 50 feet in length, while the shorter exposures on the serrated side of the building need not have individual zones. These shorter exposures may be served by adjacent zones serving other exposures.

- Each perimeter system zone is controlled by one or more thermostats located in the zones served. In the past, perimeter systems were often controlled by outdoor air sensors that would reset the output of the system proportional to outdoor air temperature. But since solar loads can offset some of the heat loss from a space, this type of control inevitably causes overheating by the perimeter system when the sun is shining and subsequent fighting with the cooling system. Even when this control is improved by solar compensation, it still can result in wasteful fighting between interior and perimeter systems due to varying internal loads. Therefore, only controls that respond to temperature within the zones served are allowed.

Example 6-M—Data Processing Rooms

Q

An office housing both workers and data processing equipment is cooled by HVAC equipment that is provided primarily to maintain space conditions for the data processing equipment. Does the equipment have to comply with the Standard or is it exempt because its purpose is primarily to cool process equipment?

A

Determining whether a system is serving a process role or comfort conditioning role can be complicated when the space is occupied by both workers and process equipment. In general, if the HVAC system is no different than it would be for comfort applications, then it must comply with the Standard. However, if the equipment includes special humidification and dehumidification systems designed to maintain tight humidity and temperature control not normally required for comfort applications, then it is considered a process application and need not comply with the Standard.

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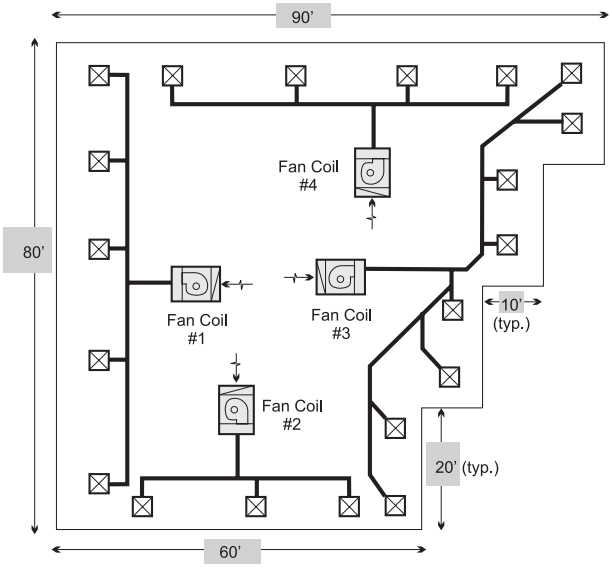

Figure 6-C—Perimeter System Zoning

In Figure 6-B, this requirement might be met by controlling the perimeter fan coil off of one of the thermostats that controls one of the four interior system VAV zones on the exposure. Alternatively, all four thermostat signals could be monitored and the one requiring the most heat used to control the fan coil. Finally, a completely independent thermostat could be installed in one of the rooms on the exposure to control the fan coil, set to a setpoint below those controlling the VAV boxes and interlocked with the other thermostats as required by § 6.4.3.2.

Deadband Controls (§ 6.4.3.1.2)
Zone thermostatic controls that control both space heating and cooling must be capable of providing a temperature range or deadband of at least 5°F within which the supply of heating and cooling to the space is shutoff or reduced to a minimum.

Figure 6-D shows a proportional control scheme that meets this requirement. This might apply to a VAV zone where the cooling source is cold supply air while heating is provided by reheat or perhaps an independent perimeter heating system. The point from where the cooling supply is shutoff or reduced to its minimum position to where the heating is turned on is called the deadband and must be adjustable to at least 5°F.

The deadband requirement is typically met using dual setpoint thermostats, which are essentially two thermostats built into the same enclosure. One thermostat controls heating and one controls cooling. The deadband can be achieved by setting the two setpoints at least 5°F apart. (For proportional controls such as pneumatic controls that are calibrated so that the thermostat setpoint is at the midpoint of the control band, the setpoints would have to be set apart by at least 5°F plus one throttling range. For instance, in Figure 6-D, the throttling range (the temperature difference between full heating and no heating, and between full cooling and no (or minimum) cooling) indicated is 2°F, so the deadband would be maintained by a heating setpoint of 69°F and a cooling setpoint of 76°F.)

Another type of pneumatic thermostat that would meet the requirement is a so-called deadband or hesitation thermostat. This thermostat is designed to provide a temperature range within which its output signal is neutral, calling for neither heating nor cooling.

Exceptions to § 6.4.3.1.2

a. Deadband controls are not necessary for thermostats that require manual changeover between heating and cooling. This is typical of many residential thermostats. The reason for this exception is that occupants will generally allow the space temperature to swing considerably before changing the heating/cooling mode, thereby causing an effective deadband.

b. Thermostats in spaces that have special occupancies where precise space temperature control is required need not have deadband control, when approved by the authority having jurisdiction. Examples include areas housing temperature-sensitive equipment or processes such as hospital operating rooms or sensitive materials such as a museum or art gallery. Other examples where deadband control may not be appropriate include homes for the aged, who may be sensitive to wide temperature swings. Buildings that do *not* fall in this category (that is, buildings where

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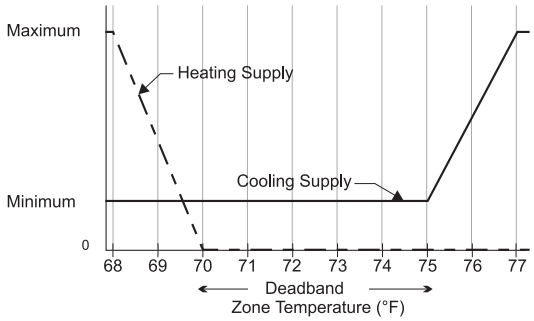

Figure 6-D—Sample Deadband Thermostatic Control

deadband controls are appropriate) include data processing centers, office buildings, retail stores, schools and hotels

Note that data processing centers were exempt in editions of 90.1 prior to 2007. However, recent research, some reported in the ASHRAE Thermal Guidelines for Data Processing Environments shows that electronic equipment can operate under more relaxed temperature and humidity conditions and the exemption is no longer justified.

Setpoint Overlap Restriction (§ 6.4.3.2)
HVAC systems commonly include two or more thermostatic controls serving the same zone. Examples include:

- Dual setpoint thermostats required by § 6.4.3.1.2 to provide a deadband between heating and cooling.
- Independent heating and cooling control loops in DDC zone controllers, again required by § 6.4.3.1.2 to provide a deadband.
- Independent heating systems such as that described above in the exception to § 6.4.3.1 controlled by a thermostat separate from those controlling the interior system.
- More than one air-conditioning unit serving a large single space, such as a large data entry area or computer room.

In each case, it is possible for one control zone to fight with the others if their setpoints are close to each other. For instance, in the case of an independent heating system with a separate thermostat, the heating setpoint could inadvertently be set to a setpoint higher than the setpoint for the interior cooling system, causing simultaneous heating and cooling supply to each space.

To prevent this inefficiency from occurring, the Standard requires that where heating and cooling to a zone are controlled by separate zone thermostatic controls located within the zone, means shall be provided to prevent the heating setpoint from exceeding the cooling setpoint minus any applicable proportional band. Examples of acceptable means include:

- Mechanical stops that prevent setpoints from being adjusted cooler (for a cooling thermostat) or warmer (for a heating thermostat) than a given value. This is commonly used on dual setpoint pneumatic thermostats.
- Mechanical stops that prevent heating setpoints from being below cooling setpoints, and vice versa. This is a common approach for electric thermostats using a physical stop on the setpoint adjustment levers that prevent the two setpoints from overlapping.
- Limits in software programming for DDC systems that prevent thermostat setpoints from overlapping.

Off-Hour Controls (§ 6.4.3.3)
Most HVAC systems serve spaces that are occupied intermittently. To reduce HVAC system energy usage during off-hours, the Standard requires that HVAC systems be equipped with automatic off-hour controls required by Sections 6.4.3.3.1 to 6.4.3.3.4).

The Standard mandates these controls for HVAC systems that have either a design heating capacity or a design cooling capacity greater than 15,000 Btu/h (4.4 kW). This means that this section does not apply to systems that only ventilate (since these systems would have no heating or cooling capacity))

Historically, heat pump systems with electric resistance heat were considered less efficient when operated intermittently because of the increased use of the resistance heat during warm-up. But this increase is mitigated by the use of proper controls that lock out the auxiliary heat when the heat pump can handle the load (controls that are required by § 6.4.3.5).

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Exceptions to § 6.4.3.2a

a. HVAC systems intended to operate continuously. Examples include hospitals, police stations and detention facilities, computer rooms, and some 24-hour retail establishments.

b. HVAC systems having a design heating capacity and cooling capacity less than 15,000 Btu/h (4.4 kW) that are equipped with readily accessible manual on/off controls.

Editions of Standard 90.1 previous to 2007 exempted hotel guest rooms from this off-hour control requirement, but several approaches are available for hotel designers to meet the requirement.

The simplest system is a stand-alone unit that resets temperature and fan levels on the HVAC unit when the guest leaves the room. There are three main components to this system: a door switch, a "people detector," and a relay. The people detector is both an occupancy sensor and logic device. In combination with the door switch, it runs through a protocol after a delay to evaluate whether someone had left the room. If so, then it resets the temperature to a preset level. This level is determined by management and preprogrammed into the control at installation time.

Advanced systems may also be used which take action based upon occupancy or opening and closure of doors can offer hoteliers a wide array of options. As an energy management control system, it can employ the simple system as part of its inputs. It then also monitors or controls guestroom locks and minibar access and enables remote central control for reprfogramming, as well as HVAC and lighting operation during unoccupied times.

Example 6-N—Deadband Requirement, DDC System

Q

A direct digital control (DDC) system using a space sensor and a "smart" controller is to be used to control a VAV box with hot water reheat. Does it have to meet the deadband requirement?

A

Yes. This system qualifies as a "zone thermostatic control" although it uses a space sensor and computer rather than a conventional thermostat to control space temperature. The software in the "smart" controller would have to support two separate control loops with individual setpoints, one for heating and one for cooling, each with separate output signals connecting to the VAV damper and reheat control valve, respectively.

Example 6-O—Deadband Requirement, Single Setpoint Thermostat

Q

A single setpoint thermostat is proposed to control a VAV box with hot water reheat. Since the thermostat can be adjusted in the winter to setpoints appropriate for heating, then changed in the summer to a setpoint 5°F higher, does it meet the deadband requirement?

A

No. This does not meet the intent of this section. The deadband must be continuous and automatic.

Example 6-P—Deadband Requirement, Pneumatic Thermostat

Q

A single setpoint pneumatic thermostat is proposed to control a fan coil that has cooling coil and an electric heating coil. The cooling coil control valve operates over a 2 to 7 psi range while the pressure switch for the heating coil is set to turn on the heat at 16 psi and off at 14.5 psi. Since there is a 7.5 psi range between the cooling and heating operating points, does this comply with the deadband requirement?

A

No. Typically, pneumatic thermostat gains are calibrated in the range of 2 to 2.5 psi per degree. The 7.5 psi deadband would then correspond to about 3°F to 4°F, not the 5°F required. To meet the requirement, the thermostat gain would have to be 1.5 psi per degree, which would cause about a 20°F swing between full cooling and full heating, which is not acceptable for comfort. Thus, while this design could be adjusted to meet the 5°F deadband requirement, it would not maintain reasonable space comfort at the same time. Occupants would be forced to defeat the control to maintain comfort, reducing or eliminating the associated energy savings. This does not meet the intent of the Standard.

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Automatic Shutdown (§ 6.4.3.3.1)
Other than systems exempted by the exceptions and qualifications to § 6.4.3.3, all HVAC systems must be equipped with at least one of the following controls with capability to automatically shut down the system when the spaces served are not expected to be occupied:

a. Time switch or scheduling controls that are able to start and stop the system under different time schedules for seven different day-types per week; are capable of retaining programming and time setting during loss of power for a period of at least 10 hours; and include an accessible manual override, or equivalent function, that allows temporary operation of the system for up to two hours.

b. Occupant sensor, capable of shutting the system off when no occupant is sensed for a period of up to 30 minutes.

c. A manually operated timer capable of being adjusted to operate the system for up to two hours.

d. An interlock to a security system that shuts the system off when the security system is activated.

An exception is provided for systems serving residential occupancies that allow them to operate with only two different time schedules per week.

The most common control option is the time switch or scheduling control. For unitary systems, a true seven-day electronic thermostat generally provides the minimum capabilities listed above. However, weekday/weekend (5-2) and weekday/Saturday/Sunday (5-1-1) thermostats, commonly used for residential applications, do *not* comply with this requirement except where applied to systems serving residential occupancies (per the exception to §6.4.3.3.1. For larger systems controlled by direct digital controls and energy management systems, the standard scheduling capabilities of these systems will generally meet the above requirements, however a means of manual override must be provided. Common solutions include: push-buttons on zone temperature sensors used with zone-level DDC; override buttons in common areas; and telephone interfaces that allow occupants to use touch-tone phones to request off-hour HVAC operation.

Occupant sensors are commonly used as lighting controls, but the same sensors can easily double as HVAC off-hour controls by adding an interlock wired as an input to the DDC zone controller controlling the associated HVAC zone. This contact would be programmed to temporarily operate the system in the same way that a local override button on the zone temperature sensor would.

Manual wind-up timers are perhaps the least common off-hour control option. They might be appropriate for the seldom-used conference room or meeting room.

Interlocking the HVAC system to a security system is simply a way of allowing the security system's scheduling controls to indirectly control the HVAC system.

Setback Controls (§ 6.4.3.2.2)
Setback controls include controls that provide temperature setback for heating systems and setup for cooling systems. This avoids wasting energy during unoccupied hours while still allowing a system that is shutoff during off-hours to automatically restart and temporarily operate in order to maintain the space at a setback or setup temperature setpoint. Setback control requirements are described as follows (see Appendix D for design temperatures).

- Heating system setback: Setback controls are required for heating systems located where the heating design temperature is 40°F (4°C) or less. The

Example 6-Q—Off-Hour Controls for Radiant Heating and Cooling Systems

Q

A space is heated or cooled by running hot or chilled water through radiant ceiling tiles. A 5-hp ventilation fan provides pre-heated and pre-cooled ventilation air to the space from a system with a 2,000,00-Btu/h heating capacity. Are off-hour controls required for this system?

A

There are really three systems in this example: a radiant heating system, a radiant cooling system, and a ventilation pre-conditioning system. The radiant heating and cooling systems do not require any off-hour controls per the exception to 6.4.3.3.2. The ventilation system would have to comply with § 6.4.3.3 since it has sufficient heating/cooling capacity to qualify.

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setback setpoint must be capable of being adjusted down to 55°F (13°C) or lower.

- Cooling system setup: Setup controls are required for cooling systems located where the cooling design temperature is greater than 100°F (38°C). The setup setpoint must be capable of being adjusted up to 90°F (32°C) or higher.

Setback controls prevent spaces from becoming so cold, or so hot, during off-hours that the HVAC system will not be able to bring them back to a comfortable range in a reasonable period of time. They save energy because if they are not present, systems in extreme climates are often programmed to run 24 hours at least part of the year to avoid under-cooled or under-heated spaces in the morning or possible damage to materials within the building.

While setback controls are required to have the setpoint capabilities listed above, these setpoints may not be the optimum for all applications. For buildings that are massive, or where heating or cooling capacity is marginal, it may be more energy efficient to setback temperatures only slightly from occupied setpoints. (Radiant floor and low temperature ceiling heating systems are exempt from set back requirements for this reason; their inherently slow pickup capability makes only a slight setback possible.) The best way to determine optimum setpoints is by trial and error once the building and system installations are complete. Computer simulations are also possible but not always accurate because of the very complex ways that energy is transferred into and out of and stored within building mass.

Optimum Start Controls (§ 6.4.3.1.3)
The simplest time switch or scheduling controls start systems each day based on the time of day. To ensure that the space is comfortable prior to occupancy, these controls are typically scheduled to start two or three hours prior to the expected occupancy time to allow for warm-up or cool-down. But this amount of warm-up/cool-down time is not always required. For instance, during mild weather, the space may be very near comfort conditions and require little or no warm-up/cool-down period. To eliminate this unnecessary system operating time, optimum start controls were developed.

Ideally, optimum start controls will start the system to provide just enough warm-up or cool-down time to bring the spaces served by the system to occupied setpoint temperatures at exactly the occupied hour, no sooner and no later. In practice, this ideal control is not possible but can be approached depending on the sophistication of the control algorithm. The Standard requires that the control algorithm must, as a minimum, be a function of the difference between space temperature and occupied setpoint and the amount of time prior to scheduled occupancy. More sophisticated algorithms include an adjustable or self-tuned mass/capacity factor that reflects the thermal mass of the building and the capacity of the heating and cooling systems. Optimum start controls are required for individual heating and cooling air distribution systems with a total design supply air capacity exceeding 10,000 cfm, served by one or more supply fans.

Zone Isolation (§ 6.4.3.1.4)
Large central systems often serve zones that are occupied by different tenants and may be occupied at different times. When only a part of the building served by the system is occupied, energy is wasted if unoccupied spaces are conditioned. To minimize this waste, the Standard requires that systems serving zones expected to

Example 6-R—Time Controls, Equipment Room Cooling Unit

Q

An air conditioner serving an elevator equipment room in an office building and controlled by a thermostat that cycles the indoor supply fan and the compressor on calls for cooling. Does this unit need off-hour controls so that it shuts off when the building is unoccupied at night?

A

No. The equipment must be maintained at a given temperature at all times and thus qualifies for Exception (b) to § 6.4.3.2. Furthermore, when the elevators are inactive at night, the air conditioner will automatically shutoff since there is no load in the space.

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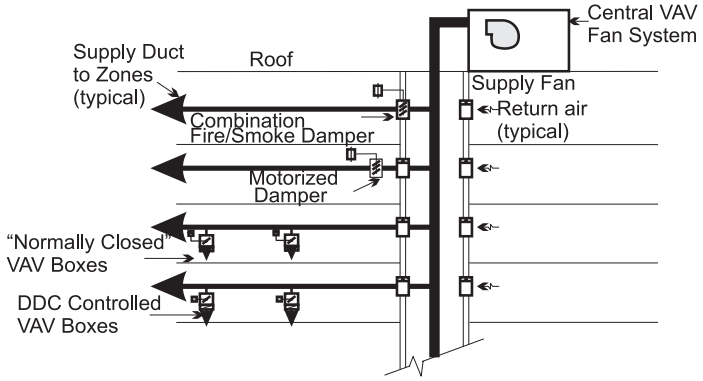

Figure 6-E—Isolation Methods for a Central VAV System

operate non-simultaneously be divided into isolation areas that can be operated as if they were independent systems.

Isolation areas can be as small as one zone, but more practically, zones will be grouped together into a single isolation area. For offices, zones may be grouped into a single isolation area provided it neither exceeds 25,000 ft² (2300 m²) of conditioned floor area nor includes more than one floor. For all other occupancies, zones may be grouped into a single isolation area provided it does not exceed 25,000 ft² of conditioned floor area or it serves only one tenant. Each isolation area must be equipped with isolation devices and controls that allow each zone to be shutoff or set back individually.

Each isolation area must include individual automatic shutdown controls meeting the requirements of § 6.4.3.2.1 as if it were a separate HVAC system. This allows each isolation zone to automatically operate on different time schedules. This is typically done using separate time switchs or scheduling programs for each isolation area. Separate off-hour timed override capability must also be provided for each zone.

Each isolation area must be equipped with isolation devices capable of automatically shutting off the supply of conditioned air and outdoor air to and exhaust air from the area. Figure 6-E shows an example of conditioned supply air control. The figure is a schematic riser diagram of a central VAV fan system serving several floors of a building, each assumed to be less than 25,000 ft². Isolation of each floor is required if they are to be occupied by tenants that can be expected to operate on different schedules, or if tenant schedules are unknown. Isolation of floors or zones may be easily accomplished by any one of the methods depicted schematically in Figure 6-E and described next:

- On the lowest floor, individual zones are controlled by direct digital controls (DDC). If the DDC software can be programmed with a separate occupancy time schedule for each zone or for a block of zones, isolation can be achieved without any additional hardware. The boxes are simply programmed to shutoff or control to setback setpoints during unoccupied periods.
- On the next floor up, zone boxes are shown to be normally closed (which means when control air or control power is removed, a spring in the box actuator causes the box damper to close). This feature can be used as an inexpensive means to isolate individual tenants or floors. The control source to each group of boxes is switched separately from other zones. When the space is unoccupied, the control source is shutoff, automatically shutting off zone boxes. A separate sensor in the space can restore control to maintain setback or set up temperatures.
- On the next floor up in Figure 6-E isolation is achieved by simply inserting a motorized damper in the supply duct.
- On the top floor, the cost of this damper is saved or reduced by using a combination fire/smoke damper at the shaft wall penetration. Smoke dampers are often required by life-safety codes to control floor airflow for pressurization. These dampers may serve as isolation devices at virtually no extra cost, provided they are wired so that life-safety controls take precedence over off-hour controls. (Local fire officials generally allow this dual usage of smoke dampers and often encourage it since it increases the likelihood that the dampers will be in good working order when a real life-safety emergency occurs.)

Note that on all floors in Figure 6-E, shutoff is not shown on floor return openings. This is because the wording of the Standard requires only that supply of conditioned air and outdoor air to, and exhaust air from, the area be shut off. In addition, with a plenum return system, the amount of air drawn off an unconditioned floor will be negligible compared to the occupied floors that have positive air supply since the latter will be pressurized.

Note also that a positive means of zone shutoff or setback is required. Shutoff VAV boxes (boxes with no minimum volume setting) cannot be assumed to

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close automatically by their thermostats during unoccupied periods due to low loads since there may be 24-hour internal loads (such as PCs, idling copy machines, or emergency lighting) and envelope loads are continuous. Either the VAV boxes must be forced closed or the thermostat setpoints must be set back/set up during unoccupied periods, as described above.

Figure 6-E doesn't show required shutoff for exhaust systems. With some exceptions (see list), exhaust air from isolation zones must be shutoff along with supply. This is particularly important in humid climates since operating the exhaust without the supply will draw moist air into building cavities and the building itself, often leading to microbial growth. Since exhaust systems seldom have VAV boxes that can be used for shutoff, complying with this section will require the use of smoke dampers or added shutoff dampers interlocked to the supply air serving the zone. Depending on the type and size of the exhaust fan, some type of duct static pressure control, such as variable speed drives, may be required as well.

Simply providing means for central system zone isolation does not end the design task. Central systems and plants must be designed to allow stable system and equipment operation for any length of time while serving only the smallest isolation area served by the system or plant.

Experience has shown that almost any fan with a variable speed drive for static pressure control can operate stably to near-zero flow. This is true even for large centrifugal fans, which will eventually pass into the surge region of their fan curves as load reduces, provided this occurs when the fan is operating below about 50% speed and static pressure setpoints are less than about 2 in. w.c. Under these conditions, fan power is reduced to the point where surge pulsations will generally have too little energy to cause objectionable noise or damage to duct systems.

Large axial fans with variable pitch blades may also be able to operate at low flows without overpressurizing ductwork. Fan curves at minimum blade pitch should be reviewed to be sure shutoff pressures are below duct design pressures.

Where fans cannot be selected to operate safely at low loads, large fans can be broken into smaller fans in parallel with operation, staged so only one fan operates at low loads.

The same considerations must be applied to central chiller plants. The plant must be able to operate at low loads for extended periods. If frequent chiller cycling is not acceptable, either multiple or staged chillers can be used. Variable speed driven chillers are also a very efficient and effective option. With variable speed drives, chillers can operate very efficiently at very low loads. As a last resort, hot-gas bypass can be used to maintain stable low load operation, but this can significantly increase energy costs and will not be as efficient as multiple staged chillers or variable speed chillers.

Exceptions to § 6.4.3.1.4

Isolation devices and controls are not required for the following:

a. Exhaust air and outdoor air connections to isolation zones when the fan system to which they connect is 5000 cfm and smaller. In other words, for exhaust fans or outdoor air ventilation fans 5000 cfm or smaller, no isolation devices (such as dampers) or controls need be installed at the fan or at any exhaust or outdoor air supply to any isolation zone served by the system.

b. Exhaust airflow from a single isolation zone of less than 10% of the design airflow of the exhaust system to

Example 6-S—Automatic Damper for Outdoor Air Intake, Packaged Air Conditioner

Q

A 7.5 ton packaged air conditioner to be installed to serve a two-story office space in Chicago, Illinois, has an outdoor air intake for minimum ventilation designed for 450 cfm. The manufacturer offers a manual outdoor air damper or a motorized damper as options. Which should be specified?

A

The outdoor air intake is designed for more than 300 cfm so it must have an automatic damper. The manual damper will not meet the requirements of this section. Chicago is in climate zone 5A, but the building is less than three stories in height, so a non-motorized gravity damper can be used. This is not one of the standard options offered by most packaged equipment manufacturers, however. Therefore, in this example, either the designer must specify a motorized damper or a separate gravity damper could be furnished by others and field installed.

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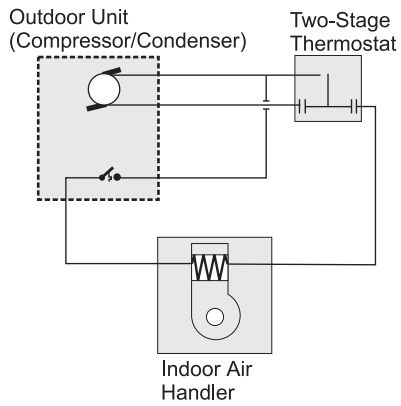

Figure 6-F—Heat Pump Auxiliary Heat Control Using Two-Stage and Outdoor Air Thermostats

which it connects. For instance, if an exhaust fan is 15,000 cfm, it is not necessary to install a damper or other device to shutoff exhaust flow from any isolation zone that is less than 1500 cfm.

c. Zones intended to operate continuously or intended to be inoperative only when all other zones are inoperative. For example, isolation would not be required for the entry lobby of a multipurpose building since it is occupied when any of the building areas are in operation. This lobby would not benefit from isolation since it would need conditioning whenever the HVAC system is on.

Ventilation System Controls (§ 6.4.3.3)

Section 6.4.3.3 covers ventilation system controls including both mechanical and nonmechanical systems. The purpose of this section is to reduce infiltration into the building when ventilation systems are off or not required. Infiltration will speed up the natural cooling or warming of the space during off-hours and thereby increase the energy required to maintain setback temperatures and possibly increase the energy use required to bring the space back to normal occupied temperatures. The Ventilation System Controls section is broken into four sub-sections:

- Stair and Shaft Vents (§ 6.4.3.3.1);
- Gravity Hoods Vents and Ventilators (§ 6.4.3.3.2);
- Shutoff Damper Controls (§ 6.4.3.3.3); and
- Dampers (§ 6.4.3.3.4).

Each subsection is described below.

Stair and Shaft Vents (§ 6.4.3.3.1)

Stair and elevator shaft vents must be equipped with motorized dampers that are capable of being automatically closed during normal building operation and are interlocked to open as required by fire and smoke detection systems. Some building codes may restrict the use of dampers in elevator shaft vents; if so, according to § 2.5, the dampers are not required.

Gravity Hoods Vents and Ventilators (§ 6.4.3.3.2)

All outdoor air and exhaust air gravity vents serving conditioned spaces must be equipped with motorized dampers designed to automatically shut when the spaces served are not in use. Gravity (non-motorized) dampers are acceptable in buildings less than three stories in height above grade and for buildings of any height located in climate zones 1–3. The reason for requiring motorized dampers in tall buildings in cold climates is, as noted under § 6.4.3.3.3, due to pressure caused by stack effect that can force gravity dampers open.

Dampers on ventilation-only systems serving unconditioned spaces are not required to meet any damper leakage requirements.

Shutoff Damper Controls (§ 6.2.3.3.3)

Both supply air and exhaust air systems larger than 300 cfm must have dampers that *automatically* close when the fan is shutoff.

Shutoff dampers must be motorized (e.g., electrically or pneumatically actuated); an exception is that gravity-type dampers (barometric shutters) may be used in buildings less than three stories high and for buildings of any height located in climate zones 1–3. The reason for requiring motorized dampers in tall buildings in cold climates is that stack effect produces high enough pressures in these climates to push open gravity dampers. Gravity dampers, where allowed, may be used on both supply and exhaust fans, although they are more commonly used just on exhaust fans.

For ventilation outdoor air supply systems, in addition to shutting the damper when the fan is off, the outdoor air damper must also shut during pre-occupancy building warm-up, cool-down, and setback, except when ventilation reduces energy costs (e.g., night purge) or when ventilation must be supplied to meet code requirements. For systems controlled by DDC, programming the damper to operate in this manner is simple. For pneumatic or electric control systems, the control is more complex. The time switch or scheduling control would have to distinguish between occupied hours and unoccupied system operation. In general, two schedules and outputs would be required, one for normal occupied hours to control the outdoor air damper along with the fan and one for warm-up/cool-down operation to control the fan but not the outdoor air damper.

Dampers (§ 6.4.3.3.4)

Where outdoor air supply and exhaust air motorized or un-motorized dampers are required per § 6.4.3.3.3 (or economizer

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supply and return dampers per § 6.5.1.1.4) they must be designed to have a leakage less than or equal to the so that presented in Table 6-B (Table 6.4.3.3.4 in the Standard) when the damper is in the closed position. Table 6-B presents the leakage requirements in cfm/ft² at 1.0 in w.c. when tested in accordance with AMCA (American Mechanical Contractors Association) *Standard 500*.

The requirements of Table 6-B are split into four categories:

- 40 cfm/ft² for non-motorized dampers that are smaller than 24 inches in either direction in climate zones 3–5. This leakage requirement can be met by standard dampers.
- 20 cfm/ft² for motorized and non-motorized dampers in climate zones 3–5. This requirement can be met by standard dampers with blade seals.
- 10 cfm/ft² for motorized dampers in climate zones 3–5. This will require low-leakage triple-vee-groove dampers with flexible metal compression jamb seals and PVC-coated polyester blade seals. (Polyurethane foam or similar blade seals ill not likely provide acceptable performance.)
- 4 cfm/ft² for motorized dampers in climate zones 1, 2, and 6–8. This will require an "ultra-low leakage" damper, typically, a damper with airfoil shaped blades, neoprene or vinyl edge seals, and flexible metal compression jamb seals. For larger dampers (those greater than 3 feet or so in width), a vee-groove type blade damper with blade and jamb seals may work.

Ventilation Fan Controls (§ 6.4.3.3.5)
Fans with motors greater than ¾ hp (0.5 kW) shall have automatic controls complying with Section 6.4.3.2.1 that are capable of shutting off fans when not required. HVAC systems intended to operate continuously are exempt from this requirement.

Heat Pump Auxiliary Heat (§ 6.4.3.4)
The heating capacity of air-source heat pumps will decrease as outdoor air temperatures fall. To make up for this deficiency, auxiliary heaters are typically installed to augment the heat output from the heat pump. With an electric resistance heater (with a COP of 1), the efficiency of the system is significantly reduced compared to the heat pump operating alone (with a COP typically greater than 2). The Standard, therefore, requires that controls be provided that prevent auxiliary heater operation when the heating load can be met by the heat pump alone, other than during outdoor coil defrost cycles.

Of primary concern is morning warm-up when the space may be well below setpoint even during relatively mild weather. The heat pump could warm the space sufficiently quickly by itself, but

Table 6-B—Damper Leakage Requirements

	Maximum Damper Leakage at 1.0 in. w.g.cfm per ft² of damper area	
Climate	***Motorized***	***Non-motorized***
1, 2, 6, 7, 8	4	Not allowed
All others	10	20[a]

Notes:
(a) Dampers smaller than 24 inches in either dimension may have leakage of 40 cfm/ft².

Example 6-T—Off-Hour Isolation Controls, Floor-by-Floor System

Q

A speculative office building is designed to have an air-handling system on each floor. What off-hour isolation provisions are required?

A

If the floors are less than 25,000 ft² of conditioned area, then each floor may be considered an isolation zone. Each fan system must be able to operate on a different time schedule.

If the floors are larger than 25,000 ft² and expected to be occupied by different tenants operating on different schedules, the system will have to be broken into more than one isolation zone. See discussion regarding Figure 6-E for ideas about how this might be accomplished.

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typical thermostatic controls would cause the auxiliary heater to operate as well, wasting energy.

The best way to resolve this problem is to use an electronic thermostat designed specifically for use with heat pumps. This thermostat can sense if the heat pump is raising space temperature during warm-up at a sufficient rate or maintaining space temperature during normal operation, and only energize the auxiliary heat if required.

More traditional electric controls can also be used, as demonstrated by Examples 6-W and 6-X. The following are required and shown schematically in Figure 6-F:

- A two-stage thermostat must be used, with the first stage wired to energize the heat pump and the second stage wired to bring on the auxiliary heat.
- An outdoor thermostat must be provided and wired in series with the second stage so that the auxiliary heat will only operate if both the second stage of heat is required and the outdoor air is cold (below setpoint).
- The outdoor thermostat setpoint must be set to the temperature at which heat pump capacity will be insufficient to warm up the space in a reasonable period of time, e.g., 40°F.

This section only applies to electric resistance auxiliary heaters since they will reduce the overall COP of the system. If auxiliary heaters such as gas furnaces are installed (generally at greater cost than resistance heaters), it is presumed that the user does so consciously and will operate the auxiliary heat to minimize utility costs. Heat pumps whose minimum efficiency is regulated by NAECA and whose HSPF (heating seasonal performance factor) rating both meets the requirements shown in Table 6.8.1B and includes all usage of internal electric resistance heating are also exempted since the use of auxiliary electric heat has already been accounted for in the equipment rating.

Humidifier Preheat (§ 6.4.3.5)

It is common with steam humidifiers to include a preheat jacket that heats up the steam injection nozzles to avoid steam condensing in the duct system when the system first starts up. The condensed steam (water) then can cause damage and may lead to microbial growth in the duct system. But when humidification is not required, the preheat jacket simply becomes a duct heater, unnecessarily heating supply air and serving no useful purpose. To avoid this energy waste, § 6.4.3.5 requires that humidifiers with preheating jackets mounted in the airstream be provided with an automatic valve to shutoff preheat when humidification is not required. Upon a call for humidification, the preheat valve would open, allowing the jacket to warm; the humidification steam control valve would then be enabled only after a temperature sensor (typically located in the steam condensate line from the preheat jacket) indicates that the jacket is sufficiently warm to prevent condensation.

Humidification and Dehumidification (§ 6.4.3.6)

Where a zone is served by a system or systems with both humidification and dehumidification capability, means must be provided to prevent simultaneous operation of humidification and dehumidification equipment. Acceptable means include mechanical stops on humidistats to prevent overlapping setpoints, electrical interlocks to prevent humidification equipment from operating when dehumidification systems are on and vice versa, and, for DDC systems, software programming to prevent overlapping setpoints.

Example 6-U—Off-Hour Isolation Controls, WLHP System

Q

A 100,000 ft² speculative office building is served by an HVAC system consisting of individual hydronic heat pumps for each zone connected to a central condenser water pump, cooling tower, and boiler. A 15,000 cfm central outdoor air fan provides ventilation air to each heat pump. What off-hour isolation devices are required?

A

The heat pumps must be grouped into isolation areas, ideally one area for each tenant. Unless they cover only one tenant or tenants that operate on similar schedules, isolation areas may be no larger than 25,000 ft² each and may include zones only from one floor. Each isolation area must include an individual time control to control the heat pumps within that area. This might be an individual time switch thermostat for each zone or for only one of the zones in the isolation area with interlocks to the other heat pumps in the area. Each isolation area control would need to be interlocked to start the central equipment as required.

The ventilation outdoor air fan also needs to include shutoff controls for each isolation area except those zones requiring less than 1,500 cfm (10% of 15,000) need not have dampers installed.

Condenser water isolation valves are not required for each isolation area since § 6.4.3.1.4 only requires the isolation of air supply and exhaust. Water could simply continue to flow through inactive heat pumps. (Automatic isolation valves at each heat pump, interlocked with its compressor, may be required if the Prescriptive Path is used. See Hydronic System Design and Control (§ 6.5.4) section.

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There are two exceptions to this requirement:

a. Desiccant cooling systems used with direct evaporative cooling in series. With these systems, air is heated and dried with the desiccant, sensibly cooled with a heat exchanger or mechanical cooling, then evaporatively cooled to achieve an outlet condition of nearly saturated air at conditions very near what would leave a conventional air-conditioning unit. Technically, this process both dehumidifies and humidifies the air, which is why this exception is provided.

b. Systems serving zones where specific humidity levels are required (such as museums, and hospitals) and approved by the authority having jurisdiction. In most cases, simultaneous humidification and dehumidification can be avoided by good design, but there are a few common applications where it cannot easily be avoided. For instance, in a hospital, cooled and dehumidified air may be provided to all zones in the hospital by a central system, while at operating rooms, local humidifiers add moisture back into the air to achieve a high humidity level that may be desired in the operating suite. Note that in editions of 90.1 previous to 2007, computer rooms were exempt, but recent research shows that this exemption is not necessary. See the ASHRAE Thermal Guidelines for Data Processing Environments.

Freeze Protection and Snow/Ice Melting Systems (§ 6.4.3.7)

Freeze protection heating systems are commonly provided on piping and equipment located outdoors or in unconditioned spaces to prevent freezing in the winter. Perhaps the most common example is electric resistance heat tracing wound around piping through which a current is run, thus heating the piping

Example 6-V—Heat Pump Auxiliary Heat Control, Two-Stage Thermostat

Q

Will a simple two-stage thermostat, wired to bring on the auxiliary heat as the second stage, meet the requirements of § 6.4.3.4?

A

No, because it will still cause auxiliary heat to be brought on during warm-up even when outdoor temperatures are mild and the heat pump has adequate capacity by itself. One of the acceptable control options listed must be provided.

Example 6-W—Heat Pump Auxiliary Heat Control, Two-Stage Thermostat with Outdoor Air Temperature Lock Out

Q

Will an outdoor thermostat, wired to lock out auxiliary heat operation during mild weather, meet the requirements of this section?

A

Yes, but used in conjunction with a two-stage thermostat and only if wired properly (see Figure 6-F). Many manufacturer's installation diagrams show outdoor thermostats wired to provide an additional thermostat stage, while using only a single-stage thermostat. It is wired so that electric heat operates with the heat pump when outdoor temperatures are cold (below the outdoor thermostat setpoint). This may cause the auxiliary heat to operate when it is not required since the heat pump may be able to meet the load even during cold weather.

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above 32°F (0ºC). When outdoor air temperatures are above freezing, it is obviously wasteful to continue to operate the freeze protection heaters. This is doubly true for heat tracing on chilled water and condenser water piping since the heating energy from the tracing becomes a cooling load.

To avoid this waste, the Standard requires that freeze protection heating systems include automatic controls capable of shutting off the systems when outdoor air temperatures are above 40°F (4.4°C) or when the conditions of the protected fluid will prevent freezing. For example, heat tracing of piping can simply be shutoff by an outdoor air thermostat set to 40°F or lower. Note that this requirement applies even if the heat tracing is so-called "self-regulated," which means that its output is automatically reduced as the temperature of the heat tracing increases. It is a common misunderstanding that self-regulated heat tracing reduces its heat output to zero at temperatures above freezing. This is not the case; while the heat output reduces at warm temperatures, it never drops completely to zero.

Snow- and ice-melting systems must include automatic controls capable of shutting off the systems when the pavement temperature is above 50°F (10°C) and no precipitation is falling. This will require a pavement temperature sensor (generally located midway between two pipes or heating cables) as well as a snow or precipitation detector. In addition, in order to ensure that the system does not run in warm weather, an automatic or manual control is required to allow shutoff when the outdoor temperature is above 40°F (4.4°C).

Table 6-C—Typical Met Levels for Various Activities

Activity	met
Seated, quiet	1.0
Reading and writing, seated	1.0
Typing	1.1
Filing, seated	1.2
Filing, standing	1.4
Walking, at 0.89 m/s	2.0
House cleaning	2.0 - 3.4
Exercise	3.0 - 4.0

Ventilation Controls for High-Occupancy Areas (§ 6.4.3.8)

Spaces with high design occupant densities offer an excellent opportunity for demand-controlled ventilation (DCV) systems since these spaces are seldom occupied at their design occupancy. DCV systems modulate the amount of outdoor air supplied to a space as a function of the number of people present, providing significant energy savings when spaces are only partially occupied. The Standard requires DCV for all ventilation systems with design outdoor air capacities greater than 3,000 cfm serving areas larger than 500 ft² and having an average design occupancy density exceeding 40 people per 1,000 ft². This typically includes assembly spaces such as theaters, meeting rooms, ballrooms, etc. As an alternative to DCV, systems may be provided with air-to-air heat recovery systems complying with § 6.5.6.1.

DCV systems must maintain ventilation rates in accordance with ANSI/ASHRAE *Standard 62.1* and local standards. Appendix A of the Standard 62.1-2004 User's Manual has a recommended procedure designing and controlling demand control ventilation systems.

Since most ventilation codes prescribe outdoor air rates proportional to the number of people in a space, it follows that a DCV system should modulate outdoor air as a function of the number of people. The most commonly used indicator of the number of people present in a space is carbon dioxide (CO_2) concentration. People give off CO_2 and other bioeffluents (including body odor) at a rate proportional to their activity level. Hence, CO_2 concentration is a good indicator of bioeffluent concentration and thus is ideal for DCV.

HVAC System Insulation (§ 6.4.4)

Installation of Piping and Ductwork Insulation (§ 6.4.4.1.1)

Required piping and ductwork insulation must be installed in accordance with industry-accepted standards such as those described in the Midwest Insulation Contractors Association's (MICA) *1999 National Commercial & Industrial Standards Manual***.** In addition, insulation that is subject to damage must be protected. For instance, insulation that may be damaged by workers maintaining equipment (e.g., if it has to be walked on or over to access equipment) must be protected from damage, such as by enclosing it in plastic or metal jacket (piping) or canvas wrap (ductwork).

Insulation located outdoors where it may be subject to damage from sunlight, moisture, and wind must be suitable for outdoor service. For instance, fiberglass insulation must be protected by aluminum, sheet metal, painted canvas, or plastic cover. Cellular foam insulation must be similarly protected or painted with a coating that is water retardant and provides shielding from solar radiation that can cause the material to degrade.

Insulation must also be installed to prevent condensation from occurring within the insulation or on the covered duct or piping surfaces. Many insulation types, notably fiberglass, will lose much of

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their insulating properties if they become soaked with water from condensing moisture. Even if the insulation is not damaged from the moisture directly, moisture can lead to microbial growth that can cause material degradation and produce noxious odors. To prevent condensation damage, the Standard requires that chilled water piping, refrigerant suction piping, or cooling ducts located outside the conditioned space must include a vapor retardant located outside the insulation, unless the insulation is inherently vapor retardant. All penetrations and joints of the vapor retardant must be sealed.

Ductwork Insulation (§ 6.4.4.1.2)
All supply and return ducts and plenums installed as part of an HVAC air distribution system must be thermally insulated with insulation as installed and excluding film resistance having a thermal resistance (h ·ft² ·°F/Btu), equal to or greater than the values shown in Tables 6.8.2A and 6.8.2B. For ducts that can supply both heating and cooling, or are return ducts, see Table 6.8.2B. For ducts that supply heating only or cooling only or are return ducts, see Table 6.8.2A.

These tables list duct insulation requirements as a function of the duct application (cooling-only supply duct, heating-only supply duct, return air duct, and heating and cooling supply duct); climate (characterized by climate zone, which are listed in Appendix D); and the following duct or plenum locations.

- *Exterior:* Includes ducts and plenums exposed to outdoor air.
- *Ventilated Attic:* Includes ducts located in an attic that has insulation separating the attic from the conditioned space and that has louvers or grilles ventilating the attic to the outdoors. This is very common construction in small commercial buildings and residential buildings.
- *Unvented Attic with Backloaded Ceiling:* The term "backloaded" means that the insulation is located between the attic and the conditioned space. The attic is not vented to the outdoors.
- *Unvented Attic with Roof Insulation:* Insulation in this case is located on the roof above the attic. This tempers the ambient temperature in the attic somewhat compared to the backloaded attic, reducing losses and insulation requirements. The attic is not vented to the outdoors.
- *Unconditioned Space:* This includes unconditioned rooms such as equipment rooms (provided they do not qualify as indirectly conditioned spaces), and both ventilated and nonventilated crawl spaces. (See the Reference section of Chapter 5 for a description of unconditioned space.)
- *Indirectly Conditioned Space:* This includes return air plenums, shafts, and mechanical rooms that are wholly or mostly enclosed by adjacent conditioned spaces. (See the Reference section of

Table 6-D—R-Values for Common Duct Insulation Materials

Installed R-value[1] (h ·°F ·ft²)/Btu	Typical Material meeting or exceeding the given R-value[2]
1.9	½ in. Mineral fiber duct liner per ASTM C 1071, Type I
	1 in. Mineral fiber duct wrap per ASTM C 1290
3.5	1 in. Mineral fiber duct liner per ASTM C 1071, Types I & II
	1 in. Mineral fiber board per ASTM C 612, Types IA & IB
	1 in. Mineral fiber duct board per UL 181
	1½ in. Mineral fiber duct wrap per ASTM C 1290
	1 in. Insulated flex duct per UL 181
6.0	1½ in. Mineral fiber duct liner per ASTM C 1071, Types I & II
	1½ in. Mineral fiber duct board per UL 181
	1½ in. Mineral fiber board per ASTM C 612, Types IA & IB
	2 in., 2 lb/ft³ Mineral fiber duct wrap per ASTM C 1290
	2½ in., .6 to 1 lb/ft³ Mineral fiber duct wrap per ASTM C 1290
	2½ in. Insulated flex duct per UL 181
8.0	2 in. Mineral fiber duct liner per ASTM C 1071, Types I & II
	2 in. Mineral fiber Duct board per UL 181
	2 in. Mineral fiber board per ASTM C 612, Types IA & IB
	3 in., ¾ lb/ft³ Mineral fiber duct wrap insulation per ASTM C 1290
	3 in. Insulated flex duct per UL 181
10.0	2½ in. Mineral fiber board per ASTM C 612, Types IA & IB

[1] *Listed R-values are for the insulation only as determined in accordance with ASTM C 518 at a mean temperature of 75°F at the installed thickness and do not include air film resistance.*

[2] *Consult with manufacturers for other materials or combinations of insulation thickness or density meeting the required R-value.*

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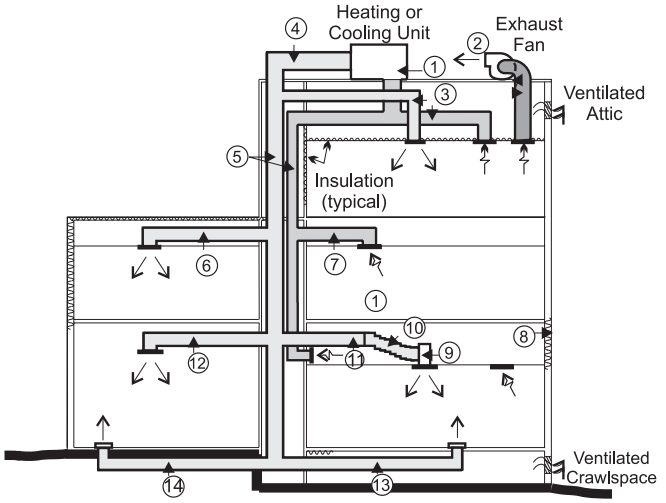
Heating or Cooling Unit
Exhaust Fan
Ventilated Attic
Insulation (typical)
Ventilated Crawlspace
KEY
1. Insulation of unit casing
2. Exhaust
3. Supply and return in vented attic
4. Supply on exterior of building
5. Supply and return in shaft
6. Supply in unvented attic
7. Return in indirectly conditioned ceiling space
8. Exterior wall of return plenum
9. Supply outlet in plenum
10. Supply runout in plenum
11. Supply in plenum
12. Supply in conditioned space
13. Supply in vented crawlspace
14. Buried supply

Figure 6-G—Duct Insulation

Chapter 5 for a description of indirectly conditioned space.) In most climates, little or no duct insulation is required for ducts located within indirectly conditioned spaces. This is because the ambient air temperature is buffered by the close coupling with the adjacent conditioned spaces so heat losses are small. In the case of return air plenums, losses are almost nonexistent since heat gained or lost to the return airstream usually reduces central heating and cooling loads.

- *Buried:* This includes ducts located within the ground. Ground temperatures a few feet below grade are cool and remain relatively constant year round.

The required minimum thicknesses in the tables do not consider water vapor transmission and possible surface condensation. Therefore, even if the R-value in the tables is low or zero, thicker insulation may be required to prevent condensation on duct surfaces or within the insulation.

Where exterior walls are used as plenum walls, wall insulation shall be as required by the most restrictive condition of § 6.4.4.1.2 or § 5. In most and perhaps all cases, the § 5 insulation requirements will be more restrictive since it is less expensive to insulate walls than ducts, allowing higher R-values to be cost-effective.

Exceptions to § 6.4.4.1.2

a. Factory-installed plenums, casings, or ductwork furnished as a part of HVAC equipment tested and rated in accordance with § 6.4.1. This exception is intended to apply to casings around tested equipment, the energy losses through which are accounted for in the energy performance tests and ratings. Although they are not always included in performance testing, optional casings such as economizer sections should also be exempted from insulation requirements if they are insulated to the same extent as the equipment to which they are attached. This is a practical requirement since designers seldom have the option to specify casing insulation levels.

This exception does not apply to air-handlers and field-fabricated plenums that do not have efficiency ratings. These systems must be insulated according to the requirements for ductwork in this section. For instance, insulation in a custom air-handler must be insulated as an exterior return air duct from the return air inlet to the coil section and insulated as an exterior supply air duct from the coil onward.

b. Ducts or plenums located in heated spaces, semiheated spaces, or cooled spaces. Heat losses and gains from these ducts usually have little or no energy impact.

c. For run-outs less than 10 ft in length to air terminals or air outlets, the rated R-value of insulation need not exceed R-3.5. This exception is intended to allow standard flexible duct with 1 in. insulation to connect terminal units even where a greater insulation thickness may be required for other ducts.

d. Backs of air outlets and outlet plenums exposed to unconditioned or indirectly conditioned spaces with face areas exceeding 5 ft² (0.5 m²) need not exceed R-2 (R-0.4); those 5 ft² (0.5 m²) or smaller need not be insulated. This exception is intended to allow ½ in. liner for plenums and duct boots, which is

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generally the only option for factory-made plenums for linear diffusers, and to obviate the need to insulate standard 2x2 ceiling diffusers.

Table 6-D shows the thickness of common materials that deliver the installed R-values listed in Tables 6.8.2A and 6.8.2B. This table is not meant to limit the use of other insulation materials that meet the minimum R-value requirements.

Example 6-X—Duct Insulation, Example System

Figure 6-G shows an HVAC system for an example building in downtown Chicago, Illinois. The insulation requirements for each duct location (climate zone 5A) identified in Figure 6-G are described below.

1. *Heating or Cooling Unit Casings and Plenums*
Exception (a) exempts casings and plenums in equipment that has an energy rating such as EER, COP, etc., since the methods used to measure this energy performance include casing losses. Therefore, if this unit is a unitary product, no duct insulation requirements apply. For air-handlers and other nonrated products, the unit casing would have to be insulated as if it were duct exposed to the outdoors.

2. *Exhaust Ductwork*
Exhaust ductwork need not be insulated since it is not covered in Tables 6.8.2A and 6.8.2B. In most applications, insulating exhaust ducts will have no impact on building energy usage.

3. *Supply and Return Ducts in Vented Attic*
These ducts are located in an attic that is vented to the outside. According to Table 6.8.2A, if the HVAC unit is cooling-only, the supply ducts in this location would require R-1.9 insulation. For a heating-only system, the supply ducts would require R-3.5 insulation. According to Table 6.8.2B, this jumps to R-6 if the unit provides both heating and cooling. According to Table 6.8.2A, return air ducts require R-3.5 insulation.

4. *Supply and Return Ducts on Exterior of the Building*
Exposed ductwork insulation requirements for Chicago are R-6 for heating-only and heating/cooling ducts, and R-3.5 for cooling-only and return air ducts.

5. *Supply and Return Ducts in Unconditioned Space*
The shaft as shown in the figure is an unconditioned space since the shaft wall between the shaft and the conditioned spaces is insulated while the outside shaft wall is not. Hence, according to the tables, no insulation is required for heating-only and return air ducts, R-1.9 is required for cooling-only ducts, and R-3.5 is required for heating/cooling ducts.

6. *Supply and Return Ducts in Unvented Attic with Roof Insulation*
Here the ducts are located within an unventilated attic with roof insulation on the top. Hence, according to the tables, no insulation is required for heating-only and return air ducts, R-1.9 is required for cooling-only ducts, and R-1.9 is required for heating/cooling ducts.

7. *Supply and Return Ducts in Indirectly Conditioned Ceiling Space*
In this case, the ducts are located in a ceiling attic that is not significantly exposed to the outside and therefore qualifies as an indirectly conditioned space. No insulation is required for these ducts.

[continued on next page]

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Example 6-X—Duct Insulation, Example System *[continued]*

8. *Exterior Wall of Return Plenum*

In this area, the ceiling space is being used as a return plenum. The exterior walls of the space are effectively return duct walls exposed to the outside. This wall must be insulated to the more restrictive requirement of either the building envelope as in § 5 or the requirements for ducts located in the exterior of the building (case 4). In most cases, the § 5 building envelope requirements will be more stringent.

9. *Supply Outlet in Return Plenum*

The plenum surrounding the air outlet is part of the supply duct system and therefore should be insulated the same as the supply ducts (case 11). However, Exception (d) allows this plenum to be minimally insulated to R-2 if more than 5 ft² in area and be uninsulated if 5 ft² or less in area.

10. *Supply Run-Out in Return Plenum*

According to Exception (c), a run-out of up to 10 ft to a terminal device (supply outlet or VAV box) need only be insulated with R-3.5. This is intended to allow standard flexible duct with 1-in. insulation (about R-4.0) to be used. Flexible duct with 2 in. insulation is not commonly available. This exception holds even if the supply ducts are required to have R-6.0, R-8.0, or R-10.0 insulation.

11. *Supply Ducts in Return Plenum*

Return air plenums qualify as indirectly conditioned spaces because of the large amount of air being drawn through them. This is so even when they are exposed to a roof above, similar to case 6. Ducts located in return plenums need not be insulated.

12. *Supply and Return Ducts in Conditioned Space*

According to Exception (b), supply and return ducts located in the conditioned space do not require insulation. From a practical viewpoint, insulation may be desirable on cooling ducts to prevent condensation if the duct passes near local areas of high humidity as might occur in a kitchen. For typical spaces, condensation will generally not occur even at very low supply temperatures since the space relative humidity will be lowered correspondingly by the dry air supply.

13. *Supply and Return Ducts in Vented Crawl Space*

Vented crawl spaces are considered unconditioned spaces (see case 5).

14. *Supply and Return Ducts Below Grade*

For this climate ducts located underground must be insulated with R-3.5 for combined heating/cooling and heating-only air ducts. No insulation is required for cooling-only and return air ducts.

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Piping Insulation (§ 6.4.4.1.3)
All piping associated with HVAC systems must be thermally insulated in accordance with Table 6.8.3. The values in this table are minimum thicknesses of insulation having a conductivity falling in the range listed, when tested at the mean rating temperature listed, for each fluid design temperature range category. These conductivities are typical of fiberglass and most elastomeric foam insulation, which are the most commonly used insulation materials.

If a less common insulation product is to be used, such as cellular glass or calcium silicate, then the thicknesses listed in Table 6.8.3 must be adjusted by the following equation:

$$T = r\left[\left(1 + \frac{t}{r}\right)^{K/k} - 1\right] \qquad (6\text{-B})$$

T = the minimum insulation thickness, in inches, for alternative material with a conductivity K.

t = the insulation thickness, in inches, from Table 6.8.3.

r = the actual pipe outside radius, inches. This is generally *not* equal to half of the nominal pipe diameter; except for piping 14 in. and larger, actual OD will be larger than the nominal diameter and depends on the piping material selected. Actual ODs can be found in standard piping tables. An abridged version for copper and steel is shown in Table 6-E.

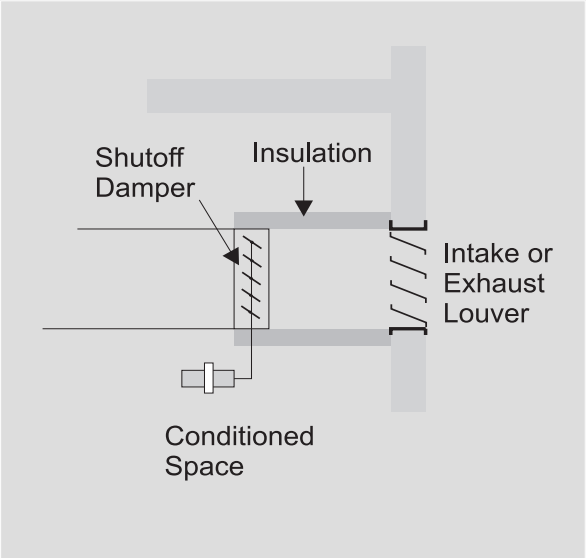
K = the conductivity of alternative material, in Btu in./(h·ft^2·°F), when measured at the mean temperature indicated in Table 6.8.3 for the applicable fluid design temperature range.

k = the upper value of the conductivity range listed in Table 6.8.3 for the applicable fluid design temperature range.

Example 6-Y—Duct Insulation at Outdoor Air and Exhaust Louvers

Q

How must the ductwork shown in the figure below be insulated when it is exposed to a conditioned space for a building in Chicago, Illinois?



A

Neither Table 6.8.2A or Table 6.8.2B addresses outdoor air ducts or exhaust ducts. For exhaust ducts, when the HVAC system is on, heat transfer from the duct to or from the space served will have little or no overall energy impact. This is also true of outdoor air intake ducts in many applications; since the outdoor air would eventually be conditioned by the HVAC system, heat losses or gains to conditioned spaces from the outdoor air in the duct would have a small net energy impact.

But what happens when the HVAC system is off? Outdoor air will infiltrate through the louver up to the shutoff damper required by § 6.4.3.3.3. Consequently, the duct between the damper and the louver is essentially part of the exterior envelope. But § 5 does not have a wall classification for "ductwork walls." The insulation requirements in § 5 were based on how practical it is to improve the insulation for each type of wall versus how much energy is saved. The insulation requirements in Table 6.8.2A and 6.8.2B were similarly developed for ductwork. It therefore makes sense to insulate this exterior wall as a duct in accord with Table 6.8.2A and 6.7.2B, as opposed to insulating the duct as if it were a wall in accord with § 5. The requirements for return air ducts exposed to the exterior should be used. For Chicago, the duct would therefore have to be insulated to R-3.5.

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Exceptions to § 6.4.4.1.3
Insulation is not regulated in the following cases:

a. Factory-installed piping within HVAC equipment tested and rated in accordance with § 6.4.1. The intent here is to exempt piping within equipment whose energy performance is tested, and piping losses are ostensibly accounted for in the ratings.

b. Piping that conveys fluids having a design operating temperature range between 60°F (16°C) and 105°F (41°C), inclusive, such as typical condenser water piping.

c. Piping that conveys fluids that have not been heated or cooled with nonrenewable energy (such as roof and condensate drains, domestic cold water supply, natural gas piping, or refrigerant liquid piping) or where heat gain or heat loss will not increase energy usage. Examples of piping falling under the latter clause of the exception are liquid and hot gas refrigerant lines on air-conditioning units and liquid lines on heat pumps.

d. Hot water piping between the shutoff valve and the coil, not exceeding 4 ft in length, where located in conditioned spaces. This is simply a practical requirement acknowledging common practice. Typically, between the shutoff valve and the coil are several valves, fittings, drains, test ports, etc., that are expensive to insulate and, given the small length of pipe, do not cause large heat losses.

e. Pipe unions in heating systems (steam, steam condensate, and hot water). This is to allow easy access to these devices.

Table 6-E—Copper and Steel Pipe Sizes

	Copper (all wall thicknesses)		Steel (all wall thicknesses)	
Nominal Pipe Size (in.)	Actual Outside Diameter (in.)	Actual Outside Radius, PR (in.)	Actual Diameter, (in.)	Actual Radius, PR, (in.)
¼	0.375	0.188	0.54	0.270
⅜	0.500	0.250		
½	0.625	0.313	0.84	0.420
⅝	0.750	0.375		
¾	0.875	0.438	1.05	0.525
1	1.125	0.563	1.32	0.658
1¼	1.375	0.6875	1.66	0.830
1½	1.625	0.813	1.90	0.950
2	2.125	1.063	2.375	1.188
2½	2.625	1.313	2.875	1.438
3	3.125	1.563	3.50	1.750
4	4.125	2.063	4.50	2.250
5			5.56	2.782
6			6.625	3.313
8			8.625	4.313
10			10.75	5.375
12			12.75	6.375

Duct Construction

Duct Sealing (§ 6.4.4.2.1)
Ducts and plenums must sealed in accordance with Tables 6.4.4.2A and 6.4.4.2B of the Standard. The first of these two tables prescribes the Seal Class that must be provided for various duct applications and locations. The second table describes what is required to attain each Seal Class.

The duct applications are listed as supply, return, and exhaust ducts. Supply ducts are broken into two duct static pressure classifications: ≤ 2 in. of water column (so-called "low pressure" ducts) and > 2 in. of water column (medium and high pressure ducts). Static pressure classifications are determined by the design engineer and establish the duct construction characteristics such as metal thickness and reinforcing requirements. Duct Seal Classes are consistent with those defined in the Sheet Metal and Air Conditioning Contractors' National Association's (SMACNA) *HVAC Duct Construction Standards – Metal and Flexible, 1995*. They establish which joints must be sealed but not how the joints are sealed. Any combination of adhesives, gaskets, and tapes, including pressure-sensitive tapes, may be used. For Seal Classes A and B, pressure-sensitive tape shall not be used as the primary sealant unless it has been certified to comply with UL-181A or UL-181B by an independent testing laboratory and the tape is used in accordance with that certification.

For Seal Class A, all joints and openings must be sealed; for Class B, transverse and longitudinal joints must be sealed; and for Class C, only transverse joints must be sealed. See Figure 6-H and the footnote to Table 6.4.4.2B for definitions of the terms "transverse" and "longitudinal."

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While the seal class definitions are consistent with SMACNA, Table 6.4.4.2A requires higher classes of duct sealing than SMACNA for similar duct applications. Therefore, simply specifying that ducts be constructed "in accordance with SMACNA" will not ensure compliance with this Standard.

Note also that the required seal classes in Table 6.4.4.2A are not consistent with the recommendations in Chapter 16 of the 1996 ASHRAE *Handbook—HVAC Systems and Equipment*, which are in some cases more stringent. The seal levels in the Handbook were established in part based on considerations other than energy savings, such as reducing unattractive smudging that can occur at leaks in ducts that are visible in the conditioned space. The stringency levels in the Standard are based on minimal energy cost-effectiveness without consideration of other application issues.

Duct Leakage Tests (§ 6.4.4.2.2)

Leakage testing is another requirement of the Standard that goes beyond the SMACNA standards. Testing is only required for duct sections of high pressure systems with a design duct pressure class rating (the maximum pressure under which the ducts are designed to operate) in excess of 3 in. w.c. Requirements for these duct sections are as follows.

- They must be identified on the drawings. This might be done by a general note stating, for instance, "All ducts downstream of the supply fan, down the duct riser, and through the fire/smoke dampers on each floor are designed to operate in excess of 3 in. w.c. and shall be leak tested." Alternatively, ductwork sections may be tagged on the plans with their design duct pressure class rating.
- They must be tested in accordance with industry accepted test procedures,

Example 6-Z—Insulation, Chilled Water Return Piping

Q

A chilled water system is designed for a chilled water supply temperature of 44°F with a 16°F range. Is insulation required on the return piping?

A

No. Chilled water return temperature will be 60°F at design conditions, so this piping would fall under Exception (b) and no insulation is required by the Standard. However, return water temperatures will often be lower at part load, and will often be lower than ambient dew point temperatures as well. Therefore, while the Standard does not require insulation, minimal insulation is required from a practical standpoint to prevent condensation, and it may be cost-effective since it reduces chiller load.

Example 6-AA—Piping Insulation, Condenser Water System with Waterside Economizer

Q

A high-rise office building has a waterside economizer. Under cooling conditions, the condenser water operates in the range of 65°F to 95°F, depending on outside conditions and cooling load. But during the winter, the cooling tower is controlled to cool water evaporatively down to 45°F. Does this piping require insulation?

A

The Standard regulates piping insulation based on fluid "design" operating conditions, which refers to the fluid state at peak cooling or peak heating design conditions. In this case, it could be argued that the condenser water is only of concern in the cooling mode since at design heating conditions, which will occur during building morning warm-up, the water economizer will be inactive. Therefore, the condenser water piping would not have to be insulated. (In this case, insulation would have very little if any energy impact anyway. However, insulation may be desirable in some locations to prevent condensation.)

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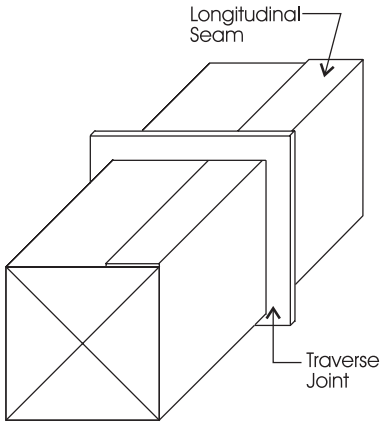

Figure 6-H—Ductwork Seams and Joints

such as those outlined in Sections 5 and 6 of the SMACNA *HVAC Air Duct Leakage Test Manual*, *1985*. To reduce costs, the entire duct system need not be tested; tests may be made for only representative sections—provided these sections represent at least 25% of the total installed duct area for the tested pressure class.

■ The maximum leakage rate when the duct is tested at a pressure equal to the design duct pressure rating must be less than that determined by Equation 6-C.

$$L_{max} = C_L P^{0.65} \qquad (6\text{-C})$$

L_{max} = the maximum permitted leakage in cfm per 100 ft² of duct surface area;

C_L = duct leakage class fixed as follows:

=6 for rectangular sheet metal ducts, rectangular fibrous ducts, and round flexible ducts;

= 3 for round/flat oval sheet metal or fibrous glass ducts;

P = test pressure, which must be equal to the design duct pressure class rating in inches w.c.

Completion Requirements (§ 6.4.5)

An energy efficient design will not result in energy efficient performance unless the system is installed, commissioned, and operated properly.

Section 6.2.5 addresses these completion requirements.

Record Drawings (§ 6.2.5.1)

The Standard requires that construction documents (plans and specifications) call for record drawings to be provided to the building owner (or owner's representative) within 90 days of system completion and acceptance.

At a minimum, the record drawings must show the location and energy-related performance data for each piece of HVAC equipment, the general layout of duct and piping distribution systems including duct and pipe sizes, and the air and water flow requirements of all terminal units, such as VAV boxes and diffusers.

Record drawings are usually the so-called "as-built" drawings prepared by the contractor showing the system design as it was installed.

Where as-built drawings are not provided, as is common on small projects, the record drawings may be the engineer's design drawings updated to show any changes to equipment location or performance.

Example 6-BB—Calculation of Pipe Insulation Thickness, Cellular Glass

Q

Cellular glass piping insulation is proposed for 10 in. chilled water lines running outdoors. (This insulation material is often preferred for outdoor installations since it is very durable and will not absorb water like fiberglass, which effectively destroys its insulating properties. There is then less concern about the quality of insulation weatherproofing.) The design chilled water supply temperature is 44°F to 54°F. What pipe insulation thicknesses are required?

A

From the manufacturer's catalog, cellular glass has a conductivity of 0.33 Btu·in./(h·ft²·°F) at 75°F mean temperature. This conductivity is outside the range listed in Table 6.8.3 (0.22 to 0.28). Therefore, the minimum insulation thickness must be determined using Equation 6-B:

$$T = 5.375\left[\left(1+\frac{1.0}{5.375}\right)^{0.33/0.28} - 1\right] \qquad (6\text{-B})$$

$$= 1.19 \; in.$$

r = 5.375 (from Table 6-E for steel pipe),
t = 1.0 in. (from Table 6.8.3),
K = 0.33 (from manufacturer's catalog),
k = 0.28 (upper value of range from Table 6.8.3).

The next largest standard size is 1½ in. insulation, which is the thickness specified in this application.

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O&M Manuals (§ 6.2.5.2)
HVAC system design documents must require that an operating and maintenance (O&M) manual or manuals be provided to the owner (or owner's representative) within 90 days of system acceptance. The manuals must conform to industry practice. ASHRAE *Guideline 4, 1993*, *Preparation of Operating and Maintenance Documentation for Building Systems* provides information and recommendations for preparing O&M manuals.

At a minimum, the manuals must include the following.

Submittal Data
Equipment size and selected options for each piece of equipment requiring maintenance must be stated. Normally submittals are provided early in the construction of a project for approval by the designer and for coordination among trades. The Standard requires that this information be made a part of the O&M manuals so that all equipment information is in one location and easily accessible by the operator. (Submittals, like specifications, tend to disappear shortly after completion of a project while O&M manuals are more likely to be retained.)

HVAC Manuals
Operating and maintenance manuals must be included for each piece of HVAC equipment requiring maintenance that is provided as part of the project. Required routine maintenance actions must be clearly identified.

Service Agency
The name and address of at least one service agency capable of providing system maintenance must be provided.

HVAC Control Information
HVAC controls system maintenance and calibration information, including wiring

Example 6-CC—Leakage Testing of Ducts, 3 in. w.c.

Q

A duct system is designed to operate at a maximum operating pressure of 3 in. w.c., but to reduce radiated noise levels, the engineer has specified that ducts be constructed to the SMACNA requirements for 6 in. operating pressure (6 in. static pressure class). What are the testing requirements for this ductwork?

A

Standard 90.1 only requires testing based on the actual design operating pressure, not the pressure that the duct might actually be able to withstand. In this case, no testing is required since the design static pressure does not exceed 3 inches.

Example 6-DD—Leakage Testing of Ducts, 4 in. w.c.

Q

If the previous example were changed so that design operating pressures were 4 in. instead of 3 in., at what pressure would the leakage tests be conducted, 4 in. or 6 in.?

A

The ductwork would be tested at 4 in. since this is the actual design operating pressure.

Example 6-EE—Record Drawings

Q

A consulting firm traditionally schedules equipment performance data in specifications rather than showing these data in equipment schedules on drawings. Does this meet the Standard's requirements?

A

No. Equipment performance must be shown on drawings, not in specifications. This is because drawings tend to be retained longer than specifications, increasing the chance that equipment performance information will be available to engineers and contractors years after the system was built. Specifications, on the other hand, tend to be lost or discarded shortly after construction.

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diagrams, schematics, and control sequence descriptions. For simple systems, such as small individual unitary equipment, a detailed system description and control schematic are not necessary to operate the system properly and thus need not be included in the O&M manuals.

For large, complex systems, control sequences and schematics are essential to proper operation and must be included.

Field determined setpoints—those determined after control system design drawings have been developed—must be permanently recorded on control drawings at control devices, or, for digital control systems, must be permanently recorded in programming comments.

For example, pressure setpoints for control of variable-volume fans and pumps, usually established after construction by the test and balance services company, must be permanently recorded in a place where they will not be easily lost. For pneumatic or electric controls, the best location is a label mounted or marked on the control device or next to the pressure gauge. For digital controls, the best location is on graphic system displays or in program comments. Recording these setpoints helps ensure that operators will operate the system as intended. Improper setpoints, such as a higher than required pressure setpoint in a variable-volume system, usually causes the system to operate less efficiently.

Operations Narrative

A complete narrative of how each system is intended to operate. This statement of design intent should be written early in the design so that as the design develops, it can be compared to the design intent as a way of ensuring that the design is on track. Once the system is built, the design intent can be used to help operators understand how to properly operate the system.

Example 6-FF—Equipment Substitutions

Q

After the design of an HVAC system, the installing contractor makes some equipment substitutions that change their energy performance. Do these changes have to be reflected on the record drawings?

A

Yes. Section 6.7.2.1 requires that the record drawings indicate the actual installation. If substitutions are made that change the energy of equipment such as A/C units, chillers, towers, etc., the record drawings must be updated accordingly. To ensure this occurs, consulting engineers should include a provision in their specifications requiring the contractor to update (or bear the cost of updating) equipment schedules and plans if contractor-initiated substitutions are made.

Example 6-GG—Balancing Requirements, Constant Volume System

Q

A constant volume single-zone system with a 3 hp fan serves several rooms, each with its own supply air and return air grille. How does the Standard require the system to be balanced?

A

The Standard requires that throttling losses must be minimized. To do this, the fan must be slowed down until at least one balancing damper is wide open. The other dampers are then adjusted to provide design airflow rates at the remaining grilles. This is often an iterative process. Finally, the outdoor air intake damper is adjusted to provide the design minimum outdoor air rate.

Example 6-HH—Balancing Requirements, VAV System

Q

A 10 hp variable air volume system has pressure-independent VAV box controls. Inlet guide vanes are use to control duct static pressure. How does the Standard require the system to be balanced?

A

The VAV boxes themselves provide balancing automatically, but the Standard still requires that throttling losses be minimized. To do this, the static pressure setpoint used to control the inlet vanes must be set so that at least one VAV box damper is wide open under design flow conditions. If the setpoint were higher, then the VAV boxes would pinch down, increasing throttling losses. This setpoint is usually determined by the air balancer in the field. In addition, fan speed must be adjusted so that design airflow conditions can be maintained with the inlet guide vanes wide open. Using the inlet vanes for balancing is not as efficient as adjusting the fan speed.

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System Balancing (§ 6.7.5.3)
Section 6.7.2.3.1 requires that construction documents call for all HVAC systems to be balanced in accordance with generally accepted engineering standards, such as the procedures published by the National Environmental Balancing Bureau (NEBB), the Associated Air Balance Council (AABC), or ASHRAE *Standard 111-1988*. An air balance report is required to be provided to the building owner or their representative for all HVAC systems serving spaces larger than 5000 ft² (460 m²).

Air System Balancing (§ 6.7.2.3.2)
Air systems must be balanced first in a manner to minimize throttling losses and then by adjusting fan speed to meet design flow rates. Fan speed adjustment is not required for fans smaller than 1 hp. See Examples 6-KK and 6-HH for typical applications.

The Standard does not specifically address what balancing devices, such as dampers or extractors, must be included or where they must be located. This is left to the designer's discretion based on past experience and guidance provided in the standards referenced in Appendix E.

Hydronic System Balancing (§ 6.7.2.3.3)
Hydronic systems are balanced in a manner similar to air systems: first, each coil or other device or terminal is proportionately balanced in a manner to minimize throttling losses; and second, the pump impeller is trimmed or the pump speed is adjusted to meet design flow conditions. Gauges or sensors (or test ports into which handheld gauges or sensors may be inserted) should be provided to measure differential pressure across the pump. This will allow overall water flow rate to be estimated from pump curves.

Example 6-II—Balancing Requirements, VAV Fan with VSD

Q

A fan serving a VAV system has a variable speed drive for static pressure control. During balancing, its full-load fan speed is found to be 20% faster than required. Do fan sheaves need to be adjusted or changed?

A

No. The Standard only requires that the fan speed be adjusted; it does not state how to do this. The sheaves may be adjusted or changed to meet this requirement, but it is more practical to allow the variable speed to automatically reduce the fan speed as required to meet system static pressure requirements. (This example applies to variable flow pumping systems as well: it is not necessary to trim the impeller to balance the system if the pump has a variable speed drive.)

Example 6-JJ—Balancing Requirements, Balancing Valves

Q

What types of balancing valves does the Standard require?

A

The Standard requires only that the system be specified to be balanced, which implies that it must be capable of being balanced. But it does not require that any particular balancing device be used. Common examples of balancing designs at coils and heat exchangers include:

- Calibrated balancing valves;
- Automatic system-powered flow control (flow limiting) valves;
- Standard ball or butterfly valves along with pressure gauges or test plugs that will allow pressure drop across the coil or heat exchanger flow to be measured and flow deduced from manufacturer's performance data;
- Pressure-independent control valves; and
- Automatic control valves (see further discussion in Example 6-KK).

Example 6-KK—Balancing Requirements, Constant Volume Pumping System

Q

A hot water heating system serves several heating coils with three-way valves. How does the Standard require the system to be balanced?

A

The Standard requires that throttling losses must be minimized. For pumps larger than 10 hp, flow through each coil would be proportionally balanced with one balancing valve wide open. If flow sufficiently exceeds design flow (see Exception (b) to § 6.7.2.3.3.), the pump impeller would then be trimmed (or pump speed reduced) to reduce flow to the design rate. For pumps 10 hp and smaller, impeller trimming or speed adjustments are not required. In this case, flow would be throttled at each coil to achieve design flow rates; it is not necessary to limit throttling losses.

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Pump speed adjustment and impeller trimming are not required for pumps with motors 10 hp or less or if throttling results in no greater than 5% of the nameplate horsepower draw, or 3 hp, whichever is greater, above that required if the impeller were trimmed. Valve throttling alone may be used for balancing such systems. As with air systems, the type of valves or other devices required to make the system capable of being balanced is left to the designer's discretion.

System Commissioning (§ 6.7.2.4)
The system commissioning process helps to ensure that building systems are designed, installed, and operating as intended. There are many levels of commissioning, from the simple start-up procedures that most contractors perform at the end of the project, to an elaborate and formal process conducted by an independent "commissioning agent" that carries through the entire design and construction process. The appropriate level of commissioning varies according to the critical nature or importance of the project, the owner's desires, and budget constraints. For a critical project, such as a hospital, a high level of commissioning is usually appropriate. For a simple, non-critical application such as a small retail store, standard start-up procedures may be adequate. For most projects, some level between these extremes is probably the most cost-effective; standard start-up procedures are usually insufficient while comprehensive commissioning is probably too time intensive and expensive for the benefits received.

Specifying the appropriate level of commissioning in a standard like *Standard 90.1* is difficult because of the wide range of criticality and complexity of systems and applications. It is also very difficult to assess the energy and operational savings from commissioning and therefore difficult to assess its cost-effectiveness. For these reasons, the commissioning requirements in Standard 90.1 are necessarily general and not overly stringent. The requirements are summarized as follows:

- HVAC control systems must be tested to assure that control elements are calibrated, adjusted, and in proper working condition. This does not necessarily require field calibration of sensors; assuring that the sensors have been factory calibrated and that they are in working order is sufficient.
- For projects larger than 50,000 ft² (4,600 m²) of conditioned area (except warehouses and semiheated spaces), an HVAC system commissioning plan must be developed by the designer and included in the design documents. The Standard does not specify the level of commissioning since the appropriate level will vary from project to project. These details are left to the designer. Guidance for developing commissioning plans can be found in ASHRAE *Guideline 1—The HVAC Commissioning Process* (ASHRAE 1996); *Procedural Standards for Building Systems Commissioning* (NEBB 1999); *HVAC Commissioning Manual* (SMACNA 1994); and *Model Commissioning Plan and Guide Specifications* (PECI 1998).

Example 6-LL—Balancing Requirements, Variable Flow Pumping System

Q

A large chilled water system serves coils with two-way control valves. How does the Standard require the system to be balanced?

A

As previously noted in Example 6-JJ, the Standard does not state how to provide a balanced system, only that it be specified to be balanced. Some systems may be designed to be self-balancing via control devices or system layout. Whether or not the system needs to be balanced in the traditional sense, where flow at each coil is measured and adjusted, is left to the professional judgment of the engineer. Either system balancing approach is acceptable from the Standard's perspective.

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Prescriptive Path (§ 6.5)

Economizers (§ 6.5.1)

Commercial buildings generally require cooling even during cool or cold weather. Interior zones—zones not adjacent to the exterior window wall—require cooling year-round. Some exterior zones with large expanses of glass, particularly if facing south or west, will require cooling during cool, sunny weather because low wintertime sun angles increase solar loads on the building. Other exterior zones may require cooling during cold weather because of high internal cooling loads from lights, people, and office equipment such as computers and copiers.

In response to this characteristic of commercial buildings, § 6.5.1 of the Standard requires that cooling systems have either an air or a water economizer, which are systems that use outdoor air as a source of cooling in place of or to supplement mechanical cooling.

Economizer Requirement Qualifications and Exceptions

The effectiveness of economizers depends on the load characteristics of the building, the type and size of the HVAC system, and the local climate. Accordingly, the Standard provides the following exceptions to the economizer requirement:

Weather and Capacity (Exception (a) to 6.5.1)

The cooler the climate, the more hours there will be when outdoor air can provide free cooling. The size of the cooling system is also a factor, since the cost of economizer controls is not proportional to cooling capacity whereas the energy savings from the economizer is proportional to cooling capacity. An economizer is required by the Standard only if the capacity of the individual cooling unit is equal to or larger than the capacity listed in Table 6.5.1 for the applicable climate.

These data can be found in Appendix D for many locations. For locations not listed in Appendix D, designers must select a location in the Appendix that has weather most similar to that found at the building site. If there are recorded historical climatic data available for a construction site, they may be used to determine compliance if approved by the building official.

Note that this exception applies to each individual unit, not to the sum of the capacities of every air conditioner in a building. In other words, if a building in Denver, Colorado (design wet-bulb = 59°F, hours between 55°F and 69°F = 739) has two air conditioners, each with 60,000 Btu/h design capacity, neither of them is required to have an economizer even though the total capacity for the building exceeds 65,000 Btu/h.

Air Cleaning (Exception (b) to 6.5.1)

In areas where the outdoor air quality is poor, designers may opt to clean the air before introducing it into the building for ventilation. ASHRAE *Standard 62* suggests that when the outdoor air quality does not meet the National Ambient Air Quality Standards (NAAQS) established by the U.S. Environmental Protection Agency (EPA), then the air should be cleaned to reduce contaminants to the NAAQS limits. For particles (PM_{10}), this is very easily done; a particle filter that is 30% efficient when rated in accordance with ASHRAE *Standard 52.1* (or MERV 6 when rated in accordance with ASHRAE *Standard 52.2*) will in most cases reduce particle concentrations to below the NAAQS limits. However, gas-phase air cleaners, such as those used to remove ozone or nitrogen oxides, are relatively expensive to install and to operate. Because of this high cost, the Standard does not require economizers on systems for which gas-phase air cleaning has been installed to meet § 6.1.2 of ASHRAE *Standard 62-1999*. This means that such systems only need to provide air cleaning for the minimum ventilation rate, not 100% of the fan's supply air capacity.

Note that even though this exception exempts systems with air cleaning from installing economizers, the designer should still consider using water economizers for these applications. Water economizers do not increase outdoor air intake rates and therefore will not increase the cost of gas-phase air cleaning systems, but they still provide energy savings comparable to air economizers.

Process Humidification (Exception (c) to 6.5.1)

Humidification loads are proportional to the amount of outdoor air the system supplies. Therefore, while air economizers reduce cooling energy use, they can increase humidification loads and corresponding energy use. The Standard does not require economizers for systems for which 25% or more of design supply air capacity is to be supplied to spaces designed to be humidified above 35°F (2° C) dewpoint temperature to satisfy process needs. Note that this exception only applies when spaces are required by "process needs" to be humidified, such as printing facilities or some areas of hospitals. It does not apply if the building is being humidified only for comfort purposes. See also Humidification Systems (§ 6.5.2.4) in this chapter.

Condenser Heat Recovery (Exception (d) to 6.5.1)

Economizers reduce energy use by using cool outdoor air to reduce cooling energy demand. Heat recovery works on the opposite principle: it reduces heating

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energy use by transferring heat rejected from spaces requiring cooling (such as interior zones) to offset the heating demand from spaces requiring heating (such as perimeter zones) or from domestic hot water. When economizers are provided, cooling equipment does not run (or runs at reduced load) in cold weather, so no heat (or little heat) is available for recovery. For this reason, the energy savings from condenser heat recovery will be significantly reduced if economizers are also used. Therefore, the Standard exempts systems that include a condenser heat recovery system required by § 6.5.6.2 from having economizers.

Note that § 6.5.6.2 only requires heat recovery for the purpose of domestic hot water usage. It does not require heat recovery for space heating. However, most systems capable of heating domestic hot water can also be configured to provide space heating as well. Energy studies indicate that in cold weather, heat recovery systems can be significantly more efficient than economizers, while in mild weather economizer systems are more efficient. The system that is the best on an annual basis depends on: the building's load characteristics (how well the envelope is insulated, how large the cooling loads are in the winter); energy rates (the fuel source for primary heating may be different from that for cooling, both of which have different costs); and, most significantly, the local climate. However, if there is a large heating load even during mild and hot weather, such as that for the domestic hot water heating system described in § 6.5.6.2, heat recovery will probably outperform economizer systems on an annual basis. A detailed computer analysis would be required to evaluate the two design options in this application.

Residential (Exception (e) to 6.5.1)
Residential buildings seldom have the high internal loads common to commercial buildings. They therefore tend to need heating when the outdoor air is cool or cold. This reduces the energy savings and cost-effectiveness of economizers. Therefore, the Standard does not require economizers for systems that serve residential spaces where the system capacity is less than five times the requirement listed in Table 6.5.1. This last clause referring to Table 6.5.1 essentially means that this exception does not apply to very large residences that behave more like commercial buildings than residential buildings.

Envelope-Dominated Space (Exception (f) to 6.5.1)
Economizers are not required for systems that serve spaces whose space-sensible cooling load at design conditions, not including transmission or infiltration loads, is less than or equal to transmission plus infiltration loads calculated at 60°F outdoor air temperature. For such envelope load-dominated spaces, economizers will not be significant energy savers because cooling loads will not occur in cold weather. To demonstrate the applicability of this exception, simply recalculate space-cooling loads at 60°F outdoor air temperature with all other design conditions unchanged. If solar and internal loads are offset by the heat losses through the envelope and by infiltration, then the system serving the space need not have an economizer.

Few Operating Hours (Exception (g) to 6.5.1)
Systems that serve spaces expected to operate fewer than 20 hours per week, such as some places of worship, are not required to have economizers. The few hours of operation reduce the energy-saving potential of the economizers, which reduces their cost-effectiveness.

Supermarket Refrigeration (Exception (h) to 6.5.1)
Economizers are not required if they adversely affect open freezer casework such as that in grocery stores and supermarkets. When the space dewpoint temperature is above freezer casework surface temperatures, water vapor condenses on case walls, causing frost. Frost partially insulates the walls from the products in the casework and from the air surrounding the product, which then requires the casework refrigeration system to operate at lower temperatures and therefore lower energy efficiency. Frost buildup also increases the frequency at which the freezer must be defrosted. Economizers exacerbate this problem by bringing in outdoor air during intermediate weather when outdoor air humidity is above the dewpoint of the casework surfaces. The energy losses due to frost buildup reduce the savings from economizers and therefore reduce their cost-effectiveness. This exception does not apply to refrigerators and casework that operate above freezing since economizers will not adversely affect their operation.

High-Efficiency Unitary Equipment (Exception (i) to 6.5.1)
Where installed in climate zones 2–4, unitary air-cooled cooling equipment that has energy efficiency ratios that meet or exceed the efficiency requirements in Table 6.3.2 are not required to have economizers. Increasing cooling efficiency and economizers both have the effect of reducing cooling energy usage. The EERs (energy efficiency ratios) in Table 6.3.2 were determined from computer simulations of typical office and retail single-zone system applications to provide

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equivalent energy performance to minimum efficiency air-conditioning units with air economizers.

Air Economizers (§ 6.5.1.1)
Air economizers (also called airside economizers) use controllable dampers to increase the amount of outdoor air drawn into the building when the outdoor air is cool or cold and the system requires cooling. To meet the Standard, economizer systems must be able to supply 100% of the design supply air quantity as outdoor air.

The Standard has specific requirements for all the major elements that compose air economizers, including:

- How the economizer dampers are modulated;
- How the economizer is shutoff when the weather is warm and no longer conducive to free cooling;
- Damper characteristics; and
- How air is relieved from the building to prevent overpressurization.

These components are shown in Figure 6-I and discussed in the following sections.

Economizer Damper Controls
It is essential for economizer dampers to sequence properly with mechanical cooling so that economizer savings can be maximized. To ensure proper sequencing, the Standard requires that the mixed air temperature not control the economizer. Instead, the dampers must be controlled by the same controller or control loop used to control the mechanical cooling, typically controlling the air-handler supply air temperature as shown in Figure 6-I.

There are two reasons why mixed air temperature should not be used to control the economizer.

- Having two control loops controlling the economizer and

Example 6-MM—Economizer Exception for Small Systems

Q

For a building in Los Angeles, two 60,000 Btu/h air-handlers supply air to a common discharge plenum. Does this qualify as one system (total capacity of 120,000 Btu/h), in which case an economizer is required, or as two individual systems (each at 60,000 Btu/h), in which case economizers are not required?

A

The rationale for the small size exception is that the energy savings cannot justify the cost of the economizer dampers, plenums, and controls. In this example, whether the air- handlers are considered a single system depends on whether a single set of economizer dampers, plenums, and controls could be used, in which case an economizer is required. If two sets of economizer devices are required (as would be the case, for instance, if the two air-handlers did not share a common mixed air plenum), each air-handler would be considered an individual system and economizers would not be required.

Example 6-NN—Economizer Exception for Systems with Condenser Heat Recovery

Q

A condenser heat recovery system is installed to preheat the peak service water draw to 80°F (equivalent to 50% of the peak heat rejection load at design conditions) for a water-cooled system with 6,500,000 Btu/h of total installed heat rejection capacity. The facility operates 24 hours a day. The design service water heating load is 1,200,000 Btu/h. Is the economizer exempt for this system?

A

No. The minimum required heating capacity of the heat recovery system is 60% of the peak heat rejection load at design conditions or to preheat the peak service water draw to 85°F.

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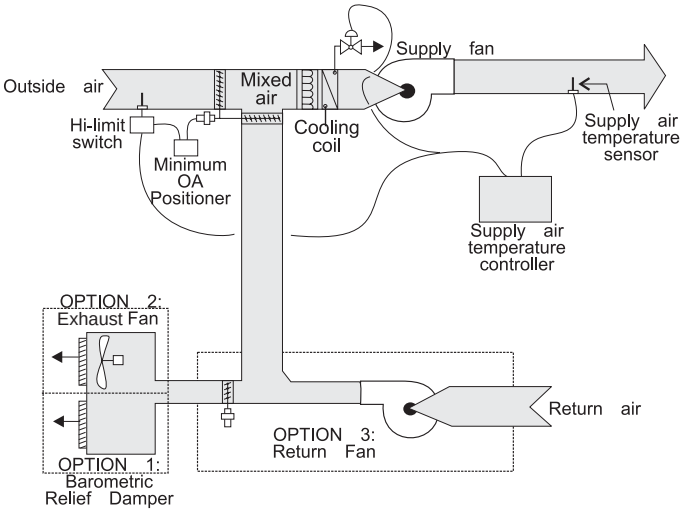

Figure 6-I—Economizer Schematic

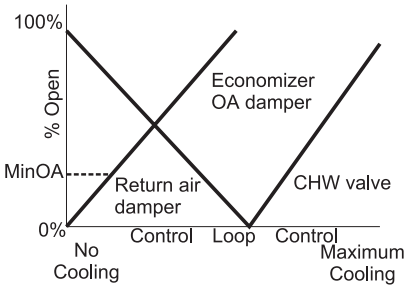

Figure 6-J—Typical Economizer Sequencing

mechanical cooling is more likely to result in improper sequencing. For instance, if the economizer were being controlled to maintain a mixed air temperature setpoint while the cooling was controlled to maintain a supply air temperature setpoint, the two setpoints must be coordinated for proper sequencing. Because of fan heat, the mixed air temperature setpoint would have to be lower than the supply air temperature setpoint. On variable air volume systems, fan heat varies, so maintaining coordination between the two setpoints is difficult. If setpoint reset strategies were used, these too would have to be coordinated.

- Mixed air temperature is very difficult to measure. Even with a serpentine averaging sensor, stratification and radiant effects from the chilled water coil can cause sensor errors.

Mixed air temperature is acceptable for controlling the economizer for systems controlled from space temperature (such as single-zone systems). This is allowed because these systems typically do not have a supply air temperature sensor from which to control the economizer; controlling the economizer from the space thermostat alone could lead to low entering air temperatures, which could lead to coil freezing.

Figure 6-J shows how outdoor air and return air dampers are typically sequenced. Sequencing can be done using a single controller by selecting sequenced spring ranges, as is typically done with pneumatic control systems. With digital control systems, sequencing is usually done through software.

For variable air volume systems, fan energy savings can be enhanced if the dampers are sequenced rather than overlapped as shown in Figure 6-J, i.e., the outdoor air damper is fully opened before the return air damper is closed. This will reduce the pressure drop through the mixing assembly during most operating conditions, which, for variable volume systems with fan volume controls, will reduce fan energy.

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High Limit Shutoff (§ 6.5.1.1.3)
As the outdoor air warms up, there will be a point where outdoor air intake will increase energy usage. At this point, the economizer must be shutoff and the system operated at the minimum outdoor air volume required for ventilation. The controller that causes this to occur is called the economizer high limit control or high limit shutoff switch.

There are several common high limit controllers.

- *Fixed Dry-Bulb Temperature High Limit:* This controller only measures the outdoor air temperature and compares it to a fixed temperature setpoint. When the outdoor air temperature is above the setpoint, the economizer is locked out; when outdoor air temperature is below the setpoint, the economizer is enabled. This is the simplest and most reliable controller since a simple thermostat placed in the outdoor air intake may be used.
- *Differential Dry-Bulb Temperature High Limit:* This control requires that both outdoor air and return air temperature be measured. The economizer is disabled when the outdoor air temperature exceeds the return air temperature.
- *Fixed Enthalpy High Limit:* With this controller, only outdoor air enthalpy is measured. This measurement is compared to a fixed enthalpy setpoint that is typical of return air enthalpy. The economizer is disabled when the outdoor air enthalpy exceeds the controller setpoint. This is the least common high limit controller.
- *Differential Enthalpy High Limit:* The enthalpy of both the outdoor air and return air are measured with this controller. The economizer is shutoff when the outdoor air enthalpy exceeds that of the return air.
- *Electronic Hybrid Enthalpy/Temperature Controllers:* Various control manufacturers produce a controller that is responsive to both outdoor air temperature and humidity but is not strictly an enthalpy switch. These controllers behave much like a combination of a fixed enthalpy and fixed temperature economizer. The setpoint on these controllers is a curve that changes as a function of outdoor air temperature and humidity, as seen on the psychrometric chart in Figure 6-K. The setpoint curve at low humidity is almost parallel to the dry-bulb lines since the coil is most likely to be dry. At higher humidity, the curve is almost parallel to the enthalpy lines since the cooling coil is more likely to be wet under those conditions. For packaged equipment, electronic enthalpy high limit switches are probably the most common high limit control options.
- *Dew Point and Dry-Bulb Temperature High Limit:* This controller applies to all climates. The economizer is shut off when outdoor air dry-bulb temperature exceeds 75°F or outdoor air dew point temperature exceeds 55°F.

Example 6-OO—Economizer Requirement for Water Source Heat Pump

Q

A water source system is proposed for a typical office building in Los Angeles, California (weather data from Appendix D, climate zone 3B). The heat pumps have EERs above 13. Are the heat pumps exempt from the economizer requirement using Exception (i) and Table 6.3.2?

A

No. Table 6.3.2 applies only to air-cooled unitary air-cooled air conditioners and heat pumps. This can be seen by the "mandatory Minimum EER" column, which refers to the EERs for air-cooled equipment. Because the rating conditions vary among different products, it is not always reasonable to directly compare EERs from different equipment types. For instance, the EERs for water-source heat pumps do not include the energy of pumps and cooling tower fans.

While water-source heat pumps are not exempted by Exception (i), all but very large ones are exempted by Exception (a). For this example in Los Angeles, heat pumps 5 tons and less (< 65,000 Btu/h) would not have to have economizers. Most ceiling-mounted heat pumps would fall under this exception.

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Control Curve	Control Curve (approx. at 50% RH) F)
A	73
B	70
C	67
D	63

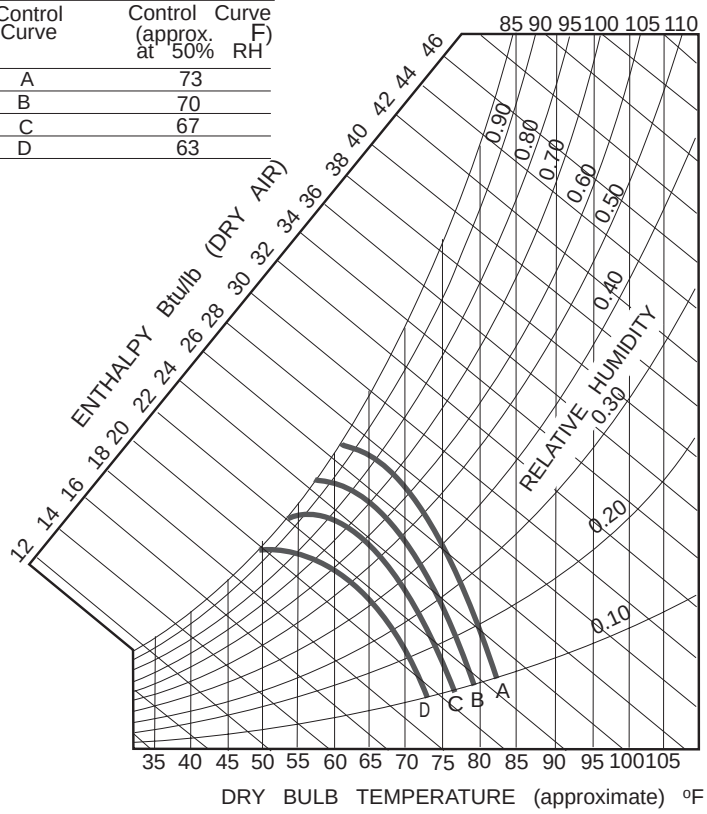

Figure 6-K—Electronic Economizer Lockout

Not all controllers are appropriate in all climates, as schematically indicated in the psychrometric chart shown in Figure 6-M. For instance, dry-bulb controllers can inadvertently cause the economizer to increase energy costs if the outdoor air is cool but moist. In these conditions, the enthalpy (the energy content of the air and water vapor mixture) of the outdoor air may exceed the enthalpy of the return air because of the high humidity, even though its dry-bulb temperature may be lower. This can increase cooling energy by increasing the latent load. Enthalpy controllers, particularly fixed enthalpy controllers, can also cause the economizer to inadvertently increase energy usage if the outdoor air is warm but dry. Under these conditions, the cooling coil may be dry, so no latent cooling is done. Although its enthalpy may be lower, cooling outdoor air may take more energy than cooling return air if its dry-bulb temperature is higher and the coil is dry.

To avoid these problems, the Standard restricts the use of some controllers in some climates and limits the setpoints of the fixed setpoint controllers, as shown in Tables 6.5.1.1.3A and B in the Standard. For instance, in humid climates, differential dry-bulb temperature controls are not allowed. If a fixed dry-bulb temperature high limit switch is used, it must be set to enable the economizer when outdoor air temperature is less than 65°F. This setpoint (and the others in Table 6.5.1.1.3B) was determined from computer simulations as the best compromise in most humid climates. If set lower, the economizer is often disabled when the outdoor air is sufficiently cool and dry to reduce cooling loads; if set higher, the number of hours when cool but moist air is introduced increases.

For the electronic and fixed enthalpy controls, the optimum setpoint is the same regardless of climate. In both cases, the setpoints correspond to the expected return air condition when the outdoor air is nearing the economizer lockout setpoint conditions, i.e., approximately 75°F and 40% to 50% relative humidity. It may seem counterintuitive that these setpoints do not vary by climate, particularly because it is counter to the advice often given in the operating instructions that accompany electronic enthalpy controllers, but it makes sense because the expected return air condition tends to be nearly the same regardless of climate.

While the Standard allows many high limit control options in most climates, not all options provide equivalent energy performance. The differential enthalpy control is theoretically the best in all but very hot and dry climates, but it costs more to install. Fixed dry-bulb controls, on the other hand, are generally the least efficient among the allowed options, but they are also the least expensive.

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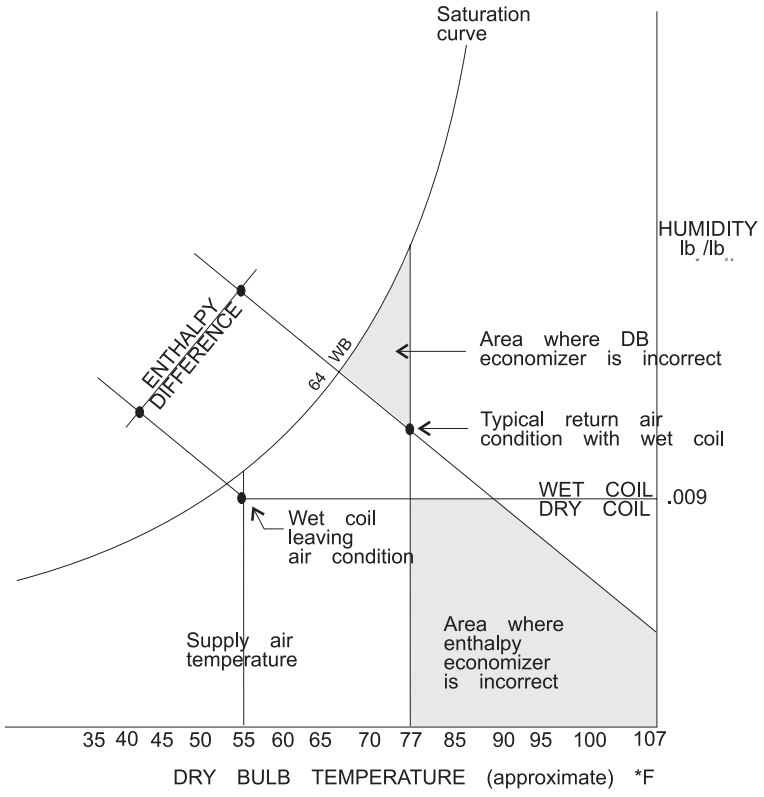
Saturation curve
HUMIDITY lb. /lb..
ENTHALPY DIFFERENCE
64 WB
Area where DB economizer is incorrect
Typical return air condition with wet coil
WET COIL
DRY COIL .009
Wet coil leaving air condition
Supply air temperature
Area where enthalpy economizer is incorrect
35 40 45 50 55 60 65 70 77 85 90 95 100 107
DRY BULB TEMPERATURE (approximate) *F

Figure 6-M—Economizer Controller Errors

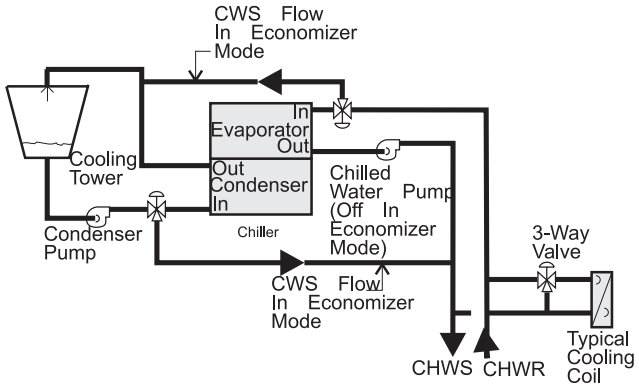

Figure 6-L—Strainer-Cycle Water Economizer

Damper Leakage (§ 6.5.1.1.4)
Return air and outdoor air dampers are required to meet the damper leakage specified in § 6.4.3.3.4 (Table 6-B). Outdoor air dampers and exhaust air dampers are required to have low leakage characteristics to prevent air infiltration and exfiltration during off-hours. But it is just as important for the return air damper to have low leakage characteristics. When the system is in the 100% outdoor air mode (when outdoor air temperatures are between about 55°F and the high-limit setpoint, which can be a majority of the economizer operating hours), leakage through the return damper will increase supply air temperatures. This forces the mechanical cooling system to operate at colder outdoor air temperatures and increases the cooling load once the mechanical cooling is on.

Economizer Relief (§ 6.5.1.1.5)
When only the code minimum ventilation rate of outdoor air is introduced by an HVAC system, the building will typically be only slightly pressurized and the excess air will exfiltrate out through the building envelope naturally. Few buildings are built so tightly or require so much minimum ventilation air that they would be over-pressurized with minimum ventilation air. That is not the case with air economizer systems. Outdoor air rates that are approximately 10 times the minimum ventilation rate can be supplied during mild weather. Without a means to relieve the air, the building will more than likely become overpressurized, causing exterior doors to stand open and causing whistling at elevator and stair doors. When these problems occur, operators are apt to disable the economizer. For this reason, the Standard requires that systems with air economizers provide a means to relieve excess outdoor air as required to prevent overpressurizing the building.

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The Standard does not specify precisely what type of economizer relief system is to be provided. There are three common relief system options (see Figure 6-I).

- *Barometric Relief:* Barometric relief uses the slightly positive building pressure to push excess air out of the building through a backdraft damper. The damper is like a check valve; it only allows air to leave the building. Schematically, relief dampers are shown in Figure 6-I near the supply fans, but they may be anywhere in the building in contact with the space or the return air path. Barometric relief systems require no control, although sometimes a shutoff damper is mounted behind the relief damper. This shutoff damper closes off the system to prevent exfiltration and associated infiltration due to stack effect when the system is off (see discussion on § 6.4.3.3.3). While they are simple and the least expensive economizer relief system option, barometric relief systems can only be used if the relief air path has a sufficiently low pressure drop to prevent overpressurization. This can be difficult to achieve in most large buildings, so barometric relief is used mostly in low-rise buildings.
- *Exhaust Fans:* When barometric relief is not practical, powered relief using relief fans may be used. These fans are usually controlled directly from building static pressure. To maximize efficiency, exhaust fans should be axial fans or propeller fans. These are the most efficient for the low pressure drops typical of return air paths such as those using the ceiling attic as return air plenums.
- *Return Fans:* Return are an alternative to exhaust fans. Exhaust fans are generally less expensive than return fans, may be placed anywhere in the return system (return fans must be placed close to the supply fans), take up less space, and are simpler to control. Exhaust fans are also more energy efficient because during noneconomizer operation, the supply fan handles the return static pressure; it is usually a more efficient fan than the return fan due to the latter's low pressure requirement (the higher the static pressure, the more efficient the fan, in general). Therefore, return fans should only be used in place of exhaust fans if the return system has a high pressure drop, for example, if it is ducted over long runs or with return air volume control boxes.

Another important consideration in the design of the exhaust system is the possibility of reentrainment of exhaust air back into the outdoor air intake. The Standard requires that the exhaust air outlet must be located to minimize recirculation into the building. No prescriptive requirements for how to achieve this goal are provided in the Standard, but the following should be avoided:

- *Exhaust Air Outlets Located Directly Below Outdoor Air Intakes:* This is common on some packaged air-conditioning units. The proximity of the exhaust to the intake and its location below the intake leads to recirculation due to the natural buoyancy of the relief air. To mitigate this problem, exhaust air can be expelled at high velocity and directed away from the intake with a hood.
- *Exhaust Air Outlets Located Within The Same Hood as the Outdoor Air Intake:* It is not uncommon in some small packaged equipment for the barometric relief damper to be located behind the same screen and hood as the outdoor air intake. Recirculation is almost guaranteed with this design. To resolve this problem, a separate barometric relief hood should be used, located as far as practical from the air-conditioning unit intake.

Water Economizers (§ 6.5.1.2)
Airside economizers use cool outdoor air directly to reduce cooling load. Water economizers (also called waterside economizers) reduce cooling load by using cool outdoor air first to cool water, which then cools supply air through a cooling coil.

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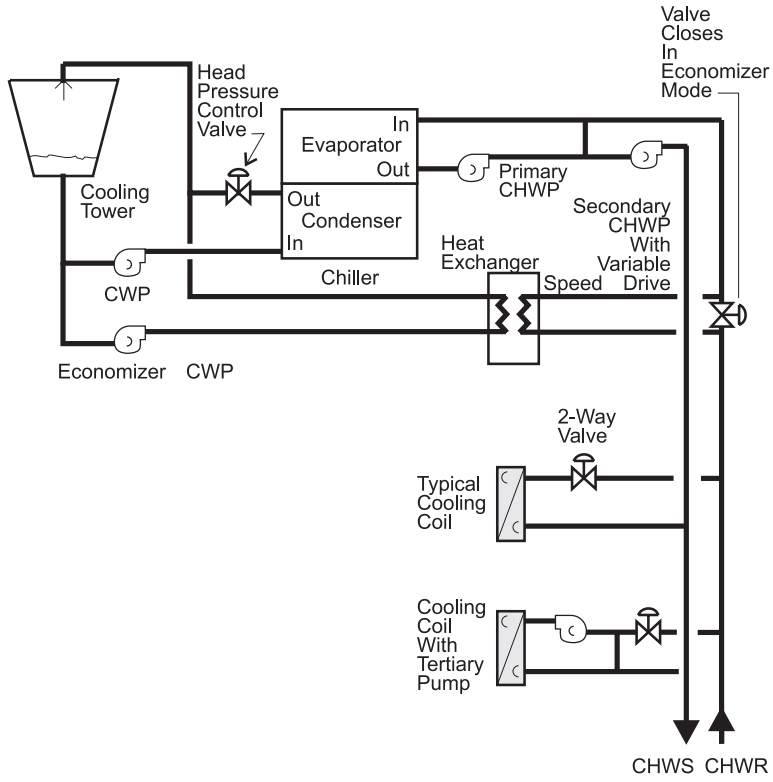

Figure 6-O—Water-Precooling Water Economizer with Two-Way Valves

The water economizer is essentially an indirect evaporative air cooler. Water is circulated through a cooling tower where it is evaporatively cooled, then circulated through cooling coils to cool supply air indirectly.

To meet the Standard, water economizers must be able to satisfy the system's entire expected cooling load when outdoor air temperatures are 50°F (10°C) dry-bulb/45°F (7°C) wet-bulb and below. This design criterion is specified because, unlike air economizers that use cold outdoor air directly for cooling, the performance of water economizers depends greatly on the selection of components such as cooling towers and heat exchangers (See Example 6-**Error! Reference source not found.**). An exception is provided when a water economizer is used in situations where dehumidification requirements cannot be met using outdoor air temperatures of 50° F (10°C) dry-bulb/45°F (7°C) wet-bulb. These systems must satisfy the entire expected cooling load at 45°F (7°C) dry-bulb/40°F (4°C) wet-bulb. This exception might apply to systems with either very low inside humidity requirements or relatively high internal latent loads. It will not apply to most office or data processing applications.

There are three common types of water economizers: strainer-cycle or chiller bypass, water-precooling, and air-precooling.

Strainer-Cycle or Chiller-Bypass Water Economizer

This type of economizer, shown in Figure 6-L, has control valves that can divert condenser water from the cooling tower and run it directly into the normal chilled water piping loop, bypassing the chiller. This bypass configuration will occur as long as the tower can cool the condenser water sufficiently to handle the cooling load, usually around 45°F to 50°F. The term strainer-cycle, as this type of economizer is commonly called, started as a trade name of a type of in-line water filter intended to clean the dirty open-circuit tower water before it flows into the clean (normally closed-circuit) chilled water circuit. Because chilled water control valves and coils can easily become clogged, it is essential to install good water treatment systems with this type of economizer. To resolve this problem, a heat exchanger can be used to isolate the tower and chilled water circuits, at both considerable first-cost expense as well as reduced energy savings due to higher pump heads and non-zero heat exchanger approach.

Note that the chiller-bypass water economizer is nonintegrated, meaning the chiller cannot operate when the condenser water is in the bypass arrangement, so the economizer either provides all of the cooling load or none of it. Because of this characteristic, this economizer design may not meet the requirements of § 6.5.1.3. (See the Economizer Integration section.)

Water-Precooling Water Economizer

This type of economizer, shown in Figure 6-N, uses cold tower water when it is available to precool chilled water return

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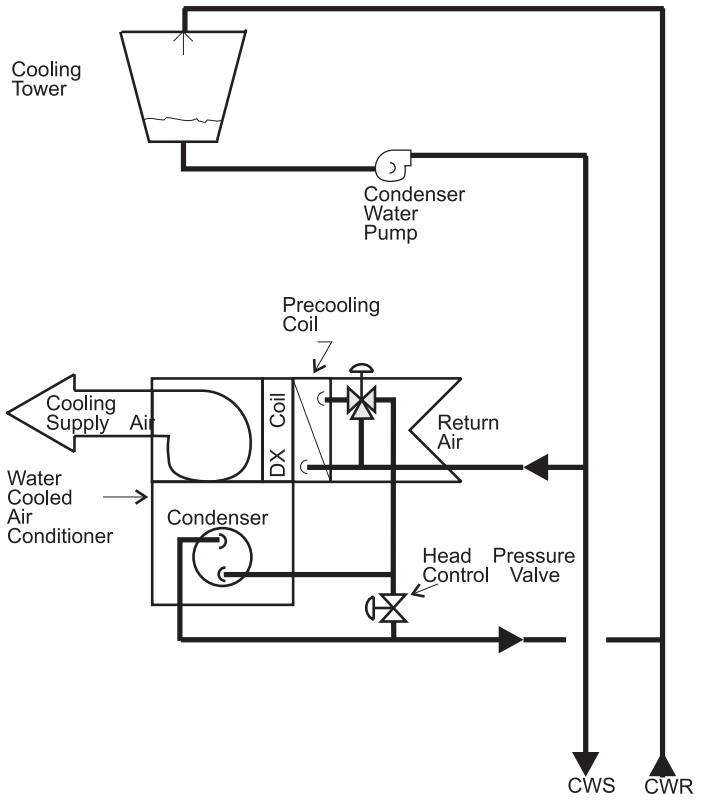

Figure 6-P—Air-Precooling Water Economizer

(through a heat exchanger) before it enters the chiller. One advantage of this type of economizer over the "strainer-cycle" is that it is "integrated," meaning it can provide "free" cooling even when the chillers are operating by reducing chilled water return temperatures. It also isolates the open-circuit tower system from the chilled water system with the heat exchanger, reducing fouling problems caused by the poor water quality of the open circuit. But the heat exchanger reduces the cooling energy savings because the water leaving the heat exchanger cannot be as cold as the tower water, and it increases pump energy during economizer operation because of the pressure drop of the heat exchanger.

While the system shown in Figure 6-N can meet the Standard, this type of economizer works best when chilled water return temperatures are kept high, which improves the heat exchanger effectiveness and allows precooling at warmer tower water temperatures. This can be achieved by using two-way valves at cooling coils, as depicted in Figure 6-O. With two-way valves, return water temperatures will actually rise above design levels at part load due to the characteristics of cooling coil heat transfer.

Air-Precooling Water Economizer

This type of water economizer requires an additional cooling coil upstream of the normal, mechanical cooling coil, as shown in Figure 6-P. Water from the cooling tower first passes through the economizer coil, precooling or fully cooling the supply air, then goes on to remove condenser heat from the mechanical cooling system, with water flow modulated or bypassed to maintain head pressures (a control required due to the cold water temperatures). The three-way control valve shown in Figure 6-P operates so that if the tower water is warmer than the return air, the water bypasses the coil to avoid warming the air and increasing the cooling load. This is similar to the high limit control used with air economizers.

Since the economizer and mechanical cooling can operate concurrently with this type of economizer, it is "integrated" and meets the requirements of § 6.5.1.3 (discussed in the Economizer Integration section). This scheme is very popular when water-cooled air conditioners are used since the condenser water must be piped to the units anyway, so the only expense of the water economizer is the added coil and controls.

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Maximum Pressure Drop

Unlike airside economizers, water economizers have parasitic energy losses that reduce the cooling energy savings. One of these losses comes from possible increases in pumping energy. To limit the losses, the Standard requires that precooling coils (Figure 6-P) and water-to-water heat exchangers used as part of a water economizer system either:

- must have a water-side pressure drop of less than 15 ft of water, or,
- a secondary loop must be created so that the coil or heat exchanger pressure drop is not seen by the circulating pumps when the system is in the normal cooling (non-economizer) mode, as shown in Figure 6-N.

Economizer Integration (§ 6.5.1.3)

The Standard requires that economizers be integrated. Integrated economizers can reduce the cooling load while the remainder of the load is met by mechanical cooling. Economizers that cannot operate simultaneously with the mechanical cooling system are called nonintegrated economizers. Integration can greatly extend economizer operation, which reduces cooling energy costs. For instance, a nonintegrated air economizer will only be able to reduce cooling energy when outdoor air temperatures are below 55°F to 60°F (Figure 6-Q), depending on required supply air temperatures. Above those temperatures, mechanical cooling is required, so the nonintegrated economizer is shutoff. If the economizer were integrated (Figure 6-R), it could continue to operate, reducing mechanical cooling energy use even though it cannot provide the entire cooling load. The integrated economizer can continue to operate until the high limit setpoint is reached, around 65°F to 75°F depending on the climate. In some climates, the outdoor air

Example 6-PP— Waterside Economizer, Performance Verification

Q

A system is designed to use the water economizer depicted in Figure 6-O. How is compliance demonstrated with the Standard's requirement that the economizer provide 100% of the expected cooling load at outdoor air temperatures of 50°F dry-bulb/45°F wet-bulb and below?

A

Because it requires knowledge of the system's performance at off-design conditions, the calculations required to demonstrate compliance are rather complicated. The following approach is suggested:

Heating and Cooling Loads. Recalculate heating and cooling loads just as they were done for design loads except change the outdoor air temperature to 50°F dry-bulb and 45°F wet-bulb. All other parameters must remain at design conditions. The economizer must be able to meet the cooling load calculated in this manner without supplemental chiller operation.

Supply Air Temperature. Determine the supply air temperature of air-handlers at the load calculated above. For VAV systems, supply air temperature should be reset upward to enhance economizer performance.

Coil Airflow Rates. Determine the coil airflow rates using the reset supply air temperature.

Chilled Water Supply Temperature. Using manufacturer's coil selection charts or programs, determine the highest chilled water supply temperature that will meet these supply air conditions assuming design water flow rates.

Chilled Water Return Temperature. The coil selection chart or program will also determine the chilled water return temperature. If there are many cooling coils, either:

- Assume conservatively that all coils will operate as required by the "worst case" coil (the one requiring the lowest chilled water temperature) or,
- Redetermine the water flow rate required and leaving chilled water temperature of all other coils assuming the chilled water supply temperature of the "worst case" coil. Determine the actual return water temperature based on the GPM weighted average of each coil's return water temperature.

Condenser Water Supply and Return Temperatures. Have the heat exchanger manufacturer determine the required cooling tower supply and return water temperatures using the following information: the chilled water supply and return temperature the chilled water flow rate and the design tower water flow rate.

Cooling Tower Performance. Verify that the cooling tower can meet the tower water flow rate and supply and return water temperatures determined above at a wet-bulb temperature of 45°F. Do this either by using manufacturer's catalog data (if available at low wet-bulb temperatures) or by having the manufacturer check performance using factory data.

If the tower can meet these conditions, then the water economizer design complies with the Standard. If not, change the tower, heat exchanger, cooling coil, or airside designs and repeat the process.

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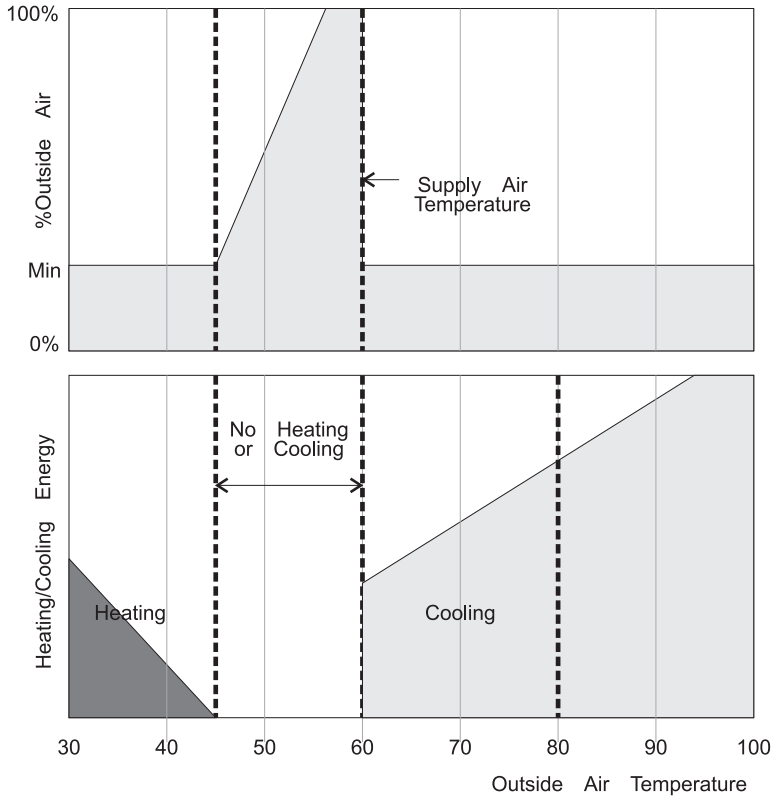

Figure 6-Q—Nonintegrated Economizer (Only Allowed by Exception)

temperature is in this range for hundreds or even thousands of operating hours.

Air economizers are usually integrated except for some that are applied to small packaged air conditioners, usually third-party or after-market products. The controls are wired so that the compressor cannot operate until the economizer has been locked out by its high limit switch, or the economizer is interlocked to shutoff when the compressor comes on.

An example of a nonintegrated water economizer is shown in Figure 6-Q; this economizer may only be used if one of the exceptions exempts the system from this requirement. The water economizers shown in Figures 6-N, 6-O, and 6-P are integrated economizers since the economizer and mechanical cooling may operate concurrently; these economizers comply with this section.

Exceptions to § 6.5.1.3

a. Direct expansion systems that include controls reducing the quantity of outdoor air as required to prevent coil frosting at the lowest step of compressor unloading, provided this lowest step is no greater than 25% of the total system capacity.

b. Individual direct expansion units having a rated cooling capacity less than 65,000 Btu/h (19 kW) and using nonintegrated economizer controls that preclude simultaneous operation of the economizer and mechanical cooling. (This exception is unnecessary since Exception (a) to § 6.5.1 exempts units this small from having to comply with this section.)

c. Systems in locations having less than 800 average hours per year between 8 a.m. and 4 p.m. when the ambient dry-bulb temperatures are between 55°F (13°C) and 69°F (21°C) inclusive. (See Appendix D of the Standard for climate data.) This exception recognizes that integrated operation is only effective when the outdoor air temperature is in the narrow band where both mechanical cooling is required and economizer operation can still reduce cooling load. When there are few hours in this range, then the benefits of integrated operation are reduced.

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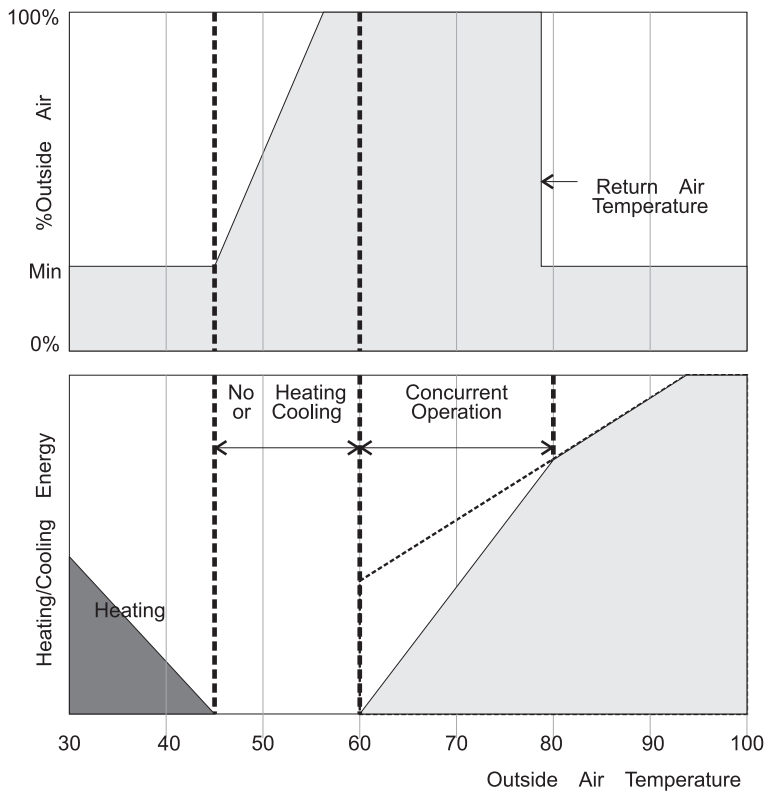

Figure 6-R—Integrated Economizer (Required)

Economizer Heating System Impact (§ 6.5.1.4)

The Standard requires that the HVAC system and economizer design and controls be such that operation of the economizer does not increase building heating energy costs during normal operation. This requirement has many implications that can significantly limit HVAC system selection and design. For instance, the single-fan/dual-duct system or multi-zone system shown in Figure 6-S would not meet this requirement with an air economizer. This is because economizer operation lowers the temperature of the air entering the hot-deck-heating coil, increasing its energy use. In order to use this type of system, a water economizer must be used, or the system must meet one of the economizer exceptions and have neither type of economizer. (Another resolution is to use a dual-fan/dual-duct system where the hot deck fan supplies only return air or return air plus minimum ventilation air. This system is often less expensive and easier to control than a single-fan/dual-duct system.)

Example 6-QQ—Water Economizer with Water Source Pump System

Q

Because of the difficulty providing air economizers with water source heat pumps mounted above ceilings, a precooling coil type of water economizer, shown in Figure 6-P, is proposed instead for each heat pump serving both interior and exterior zones of an office building. Does this design comply with the Standard?

A

No. This design can meet the requirements of § 6.5.1.2 and 6.5.1.3, but it will not meet the requirements of § 6.5.1.4, which requires that economizers be designed in a manner that will not increase the heating energy usage of the system.

With the proposed design, in cold weather the economizer will require that condenser water temperatures be cold enough to provide free-cooling in interior zones. This cold temperature, however, will increase the compressor energy required by those heat pumps serving exterior zones operating in the heating mode (the colder the water temperature, the more compressor energy required).

In most cases, economizers are not required for this type of hydronic heat pump system (see Example 6-OO). Including economizers also eliminates the energy saved from the recovery of heat from interior cooling zones to perimeter heating zones that occurs with this system.

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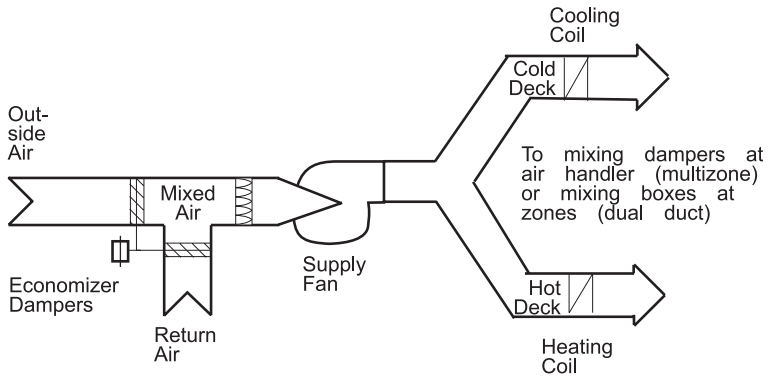

Figure 6-S—Dual-Duct or Multi-Zone System

This requirement will not affect three-deck multi-zone or "Texas" multi-zone systems since they cannot work with an air economizer in any case (it would make the neutral deck a cold deck).

An exception to the heating impact requirement is provided for economizers on VAV systems that cause zone level heating to increase due to a reduction in supply air temperature. Reducing supply air temperature on a cooling-VAV system will reduce fan energy (particularly if the system has a variable-speed drive), offsetting the energy lost due to increased reheat energy.

Simultaneous Heating and Cooling (§ 6.5.2)

Simultaneous Heating and Cooling at the Zone Level in Air Systems (§ 6.5.2.1)

As air-conditioning system designs were developed in the late 1950s and early 1960s, energy costs were a minor concern. The systems were designed primarily to provide precise temperature control with little regard for energy costs. Several techniques were used to achieve zone temperature control: reheating cold supply air (constant volume reheat system), recooling warm supply air (such as perimeter induction systems), or mixing hot and cold air (constant volume dual-duct and multi-zone systems). While these techniques provided fine temperature control, they did so by using a great deal of energy. To reduce this type of energy waste, § 6.5.2.1 of the Standard requires that zone thermostatic controls must be capable of sequencing the supply of heating and cooling to each space. These controls must prevent:

- Reheating;
- Recooling;
- Mixing or simultaneous supply of air that has been previously mechanically heated and air that has been previously cooled, either mechanically or by economizer systems
- Other simultaneous operation of heating and cooling systems to the same zone.

Single-zone systems will inherently meet these requirements, provided their controls are capable of sequencing typical heating and cooling. However, most common multiple-zone systems require the use of simultaneous heating and cooling for zone temperature control. To comply with § 6.5.2.1, these systems must use one of the three exceptions described next. The first exception is most common for standard multiple-zone systems.

Exception (a) to § 6.5.2.1
Simultaneous heating and cooling is allowed if it is minimized by limiting the airflow rate that is being reheated, recooled, or mixed to a rate not greater than the larger of the following:

- The volume of outdoor air required to meet the ventilation requirements of § 6.1.3 of ASHRAE *Standard 62-1999* for the zone.
- 0.4 cfm/ft² of the zone conditioned floor area. This 0.4 cfm/ft² criterion is a rule-of-thumb many designers feel is the minimum circulation rate that must be maintained for comfort. However, there is little empirical evidence that any minimum circulation must be maintained for comfort, and in fact *ASHRAE Standard 55* states that there is no minimum air velocity required for comfort. Nevertheless, anecdotally at least, with little or no air movement, occupants have been known to complain of stuffiness.
- 30% of the zone design peak supply rate. This limit recognizes that typical air outlet performance decreases at low flows, reducing both supply air mixing and ventilation effectiveness.
- 300 cfm. This criterion can be applied to only a limited number of zones served by the system; the total peak flow rate for all zones using this 300 cfm criterion may not total more than 10% of the total fan system flow rate. This criterion was intended to address the following applications: the occasional small zone in a VAV reheat system for which 0.4 cfm/ft² is insufficient to handle heating loads, such as spaces with large glass areas, and a small sub-zone in a single-zone system, such as that serving the entry vestibule that may require

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additional heat compared to the remainder of the zone.

- Any higher rate that can be demonstrated, to the satisfaction of the authority having jurisdiction, to reduce overall system annual energy usage by offsetting reheat/recool energy losses through a reduction in outdoor air intake in accordance with the multiple space requirements defined in ASHRAE *Standard 62-1999*. This exception is provided to allow system designers to optimally solve Equation 6-1 in *Standard 62-1999*. These equations show that the amount of outdoor air required for a system is a function of how much air is supplied to the "critical zone" in the system. The higher the supply air rate to the critical zone, the less outdoor air is required at the air-handler. The designer would determine which is more energy efficient, increasing outdoor air intake and minimizing reheat at the critical zone, or increasing the supply air rate and reheat energy required at the critical zone and minimizing the outdoor air rate. This decision may also be done dynamically in real time by an energy management system. The system would dynamically solve Equation 6-1 in *Standard 62-1999* using actual operating data (e.g., the supply air rate to the critical space and the overall system supply air rate) and would reset minimum volume setpoints and outdoor air intake rate setpoints as required to minimize energy use.

Exception (b) to § 6.5.2.1
Zones where special pressurization relationships, cross-contamination requirements, or code-required minimum circulation rates are such that variable air volume systems are impractical. This exception might apply to some areas of hospitals, such as operating rooms, and to laboratories that must be maintained at positive (or negative) pressures to prevent

Example 6-RR—Economizer Controls with Packaged AC Units

Q

A 20-ton packaged unit is required by the code to have an economizer. What specific requirements must the unit comply with?

A

As per Table 6.5.1, the unit must have an airside economizer if it exceeds the capacity limits as shown. For example, if the unit was located in Phoenix, AZ (which is in climate zone 2b), it would require an economizer for unit capacities greater than 135,000 Btu/hr. Because the capacity of this unit is 240,000 Btu/hr, it would require an economizer. An exception to the use of an economizer is allowed in this zone (§ 6.3.2), by selecting a unit with a full-load efficiency exceeding 10.6 EER.

In addition, the unit, if equipped with the economizer, would have to have the economizer integrated with the mechanical cooling (§ 6.5.1.3), so that the economizer capacity could continue to be used and supplemented with additional mechanical cooling as required by the load up to the high-limit setting. The high-limit settings depend on the type of change over control defined in Table 6.4.1.1.3A. Because this is climate zone 2b, all changeover controls can be used, except for fixed enthalpy control. The high-limit values are defined by Table 6.5.1.1.3B.

For this example, let's assume that a fixed dry-bulb change over control is selected. Then, per Table 6.5.1.1.3B, the high-limit changeover setting should be set to 75°F. This means that the unit controls should allow for the economizer to be used up to a 75°F outdoor ambient and if the load is exceeded using just the outdoor air then it shall be supplemented by mechanical cooling to satisfy the load without reducing the economizer capacity.

Example 6-SS—Strainer-Cycle Water Economizer

Q

When can the strainer-cycle water economizer shown in Figure 6-L be used?

A

This economizer is nonintegrated since the chiller cannot operate at the same time as the economizer, so it does not meet the requirement of § 6.5.1.3 of the Standard. It is only allowed under two conditions: 1) if compliance is shown via the energy cost budget method (§ 11), or 2) if the system is located in climate zones 1, 2, 3a, 4a, 5a, 5b, 6, 7, or 8. There are many areas of the country with these climate conditions where this type of water economizer may be used.

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contaminants from entering (or escaping). VAV systems have been successfully used in these applications to reduce energy costs, but control is very complicated and requires precise airflow-measuring and/or pressure-measuring instruments. The risk of a failure of these controls, such as the possible release of dangerous chemicals or bacteria, must be balanced against the potential energy savings.

Exception (c) to § 6.5.2.1
Zones where at least 75% of the energy for reheating or for providing warm air in mixing systems is provided from a site-recovered energy source (including condenser heat) or site-solar energy source.

Separating ventilation and thermal requirements—as this system does—usually results in minimal or no reheat losses, but it does not necessarily result in the best energy performance. A more energy-efficient system might be one with an outdoor air economizer that delivers outdoor air in the winter to cool interior zones, then uses transfer air to ventilate perimeter zones.

Simultaneous Heating and Cooling in Hydronic Systems (§ 6.5.2.2)

Most simultaneous heating and cooling in modern HVAC systems occurs due to air system controls as discussed in the previous section. Some energy waste, however, can also occur in hydronic systems.

Three-Pipe Systems (§ 6.5.2.2.1)
Hydronic systems that use a common return system for both hot water and chilled water, so-called three-pipe systems, cause heated water and cooled water to be mixed with each other, increasing both

Example 6-UU—Simultaneous Heating and Cooling, Exception 5 to 6.3.2.1

Q

For a VAV system, if the required outdoor air ventilation rate based on the *Standard 62-1999* multiple space equation (Equation 6-1) results in excessively high rates, may the minimum zone airflow setpoints be increased above the 30 percent in order to reduce the outdoor air flow required at the air handler?

A

Yes, exception (a)5 to § 6.5.2.1 allows the minimum airflow setpoint to be increased above 30 percent for specific critical zones under certain conditions. These critical zones have relatively high occupancy (needing a lot of outdoor air) yet have relatively low thermal load. Therefore, the outdoor air ventilation requirement in these zones is a relatively large fraction of the zones' peak supply air flow. And when thermal loads are low and the zone airflow is at its minimum setpoint, then the outdoor air requirement can be a very large fraction of the total flow. In the extreme case, the outdoor air required for a zone is equal to the minimum VAV box airflow, and 100 percent outdoor air at the air handler is required to meet the ventilation requirements of *Standard 62*'s multiple space equation. In such cases, *Standard 90.1* allows a higher minimum flow setpoint for critical zones in order to avoid the energy penalty caused by increased outdoor air ventilation rates for the overall system (at the cost of increased reheat energy in the critical zones).

For example, if a zone sized for 1,000 cfm peak airflow has a 200 cfm outdoor air requirement, then when the VAV box is at minimum flow of 300 cfm, the outdoor air fraction needed for this zone is 67 percent. Then following the *Standard 62* multiple space calculation method, the outdoor airflow required at the air handler might be on the order of 50 percent (see *Standard 62* for more details). However, if the minimum airflow setpoint for this single zone were increased from 300 cfm (30 percent) to, for example, 600 cfm, then the zone's outdoor air fraction drops to 33 percent. As a result, the outdoor air required at the air handler might drop from 50 percent to 33 percent, a significant savings, at the cost of a relatively minor increase in reheat energy.

Example 6-VV—Simultaneous Heating and Cooling, Cooling-Only Systems

Q

The interior zones of a VAV system have cooling-only VAV boxes. What limitations does § 6.5.2.1 place on the minimum volume setpoints for these zones?

A

None. Section 6.5.2.1 restricts the use of simultaneous heating and cooling. Since these zones have no heating capability, there is no possibility of simultaneous heating and cooling, so § 6.5.2.1 does not apply. (*Standard 62*, however, may require that minimum volume setpoints be placed on these boxes to ensure ventilation rates are maintained, unless it can be shown that ventilation rates will be maintained with thermostatic controls as a result of the cooling loads imposed by occupants and internal loads in the space.)

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heating and cooling energy usage. These systems are prohibited by the Standard.

Two-Pipe Changeover System (§ 6.5.2.2.2)
Two-pipe changeover systems use a common distribution system to alternately supply heated or chilled water to fan-coils and air-handlers. While operating in one mode or the other for a long period, no energy is wasted by this design. However, energy is wasted when the systems change over from one mode to the other since this requires heating or cooling the mass of water in the system. The Standard allows these systems as long as they include all the following measures to minimize the energy impact of changeovers:

- The system is designed to allow a deadband between changeover from one mode to the other of at least 15°F outdoor air temperature;
- The system is designed to and is provided with controls that allow operation in one mode for at least four hours before changing to the other mode; and
- Reset controls are provided that allow heating and cooling supply temperatures at the changeover point to be no more than 30°F apart.

Hydronic (Water Loop) Heat Pump Systems (§ 6.5.2.2.3)
Hydronic heat pumps are typically connected to a common condenser water loop as shown in Figure 6-T. Also connected to the loop are devices to add heat to the loop (a boiler) should its temperature fall too low in the winter and to remove heat from the loop (a cooling tower) should its temperature rise too high. To limit the unnecessary use of these central heating and cooling sources, the Standard requires that these systems be designed as follows.

Example 6-WW—Simultaneous Heating and Cooling, Cold Air System

Q

A VAV system is designed to supply 45°F air to VAV boxes with reheat coils. What is required for this design to meet the Standard while still meeting ventilation requirements of 0.15 cfm/ft² of outdoor air?

A

The following design and control options would allow this system to comply with § 6.5.2.1:

- *Option 1*: Fan-powered mixing boxes could be provided at each zone and minimum volume setpoints could be either zero or set equal to the minimum ventilation requirement of 0.15 cfm/ft² so that they met Exception (a-1). The controllers would have to be able to maintain this minimum volume setpoint within 10%, but that should be possible with a cold air system since maximum supply air quantities are relatively small due to the cold supply air temperature.
- *Option 2*: Supply air temperature could be reset in the winter to meet the restrictions established in Exception (a-2). Minimum volume setpoints could then be 0.4 cfm/ft², which might be sufficient to heat the space with standard VAV boxes.

Example 6-XX—Zone Control Requirements, Packaged Gas/Electric Unit

Q

A packaged gas/electric rooftop unit serves a single zone. What is required of this system to meet § 6.5.2.1?

A

The thermostat must be capable of precluding simultaneous operation of the furnace and air conditioner. The standard thermostat will do this, so the system meets this section without any added features required.

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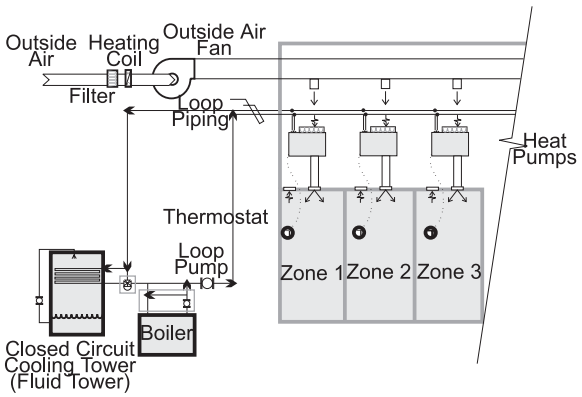

Figure 6-T—Water Loop Heat Pump System

Controls must be capable of providing a heat pump water supply temperature deadband of at least 20°F between initiation of heat rejection and heat addition by the tower and boiler. For instance, the boiler may come on when the heat pump water supply temperature drops below 60°F while the tower must be capable of being set to come on at 80°F (20°F higher). Deadband may be reduced by system loop temperature-optimization controllers that determine the most efficient operating temperature based on real-time demand and capacity conditions. Also, note that this section's 20°F deadband requirement only establishes the capability of the control system, not the actual setpoints. For some systems with high efficiency cooling towers and heat pumps whose efficiency drops significantly at lower water temperatures, a lower setpoint (e.g., 60°F to 70°F) may be optimum. To determine the optimum setpoint, a simulation program such as those discussed in Chapter 11 should be used.

In climate zones 3–8, the Standard requires that the system be designed to limit the heat loss from the heat rejection device (cooling tower), as follows:

- If a closed-circuit tower (fluid cooler) is used, either an automatic valve must be installed (see Figure 6-T) to bypass flow of water around the tower, or low-leakage positive closure dampers must be provided on the inlet or discharge of the fluid cooler to minimize natural convection across the heat exchanger due to stack effect. If a valve is installed, a minimal amount of water may be circulated through the heat exchanger to prevent freezing. Note that bypassing flow around the tower is much more effective than dampers due to damper leakage and radiant heat losses from the heat exchanger.
- If an open-circuit tower is used directly in the heat pump loop, an automatic valve must be installed to bypass all heat pump water flow around the tower. Freeze protection can be provided by sump heaters or temporarily draining the tower.
- If an open-circuit tower is used in conjunction with a separate heat exchanger to isolate the tower from the heat pump loop, then shutting down the circulation pump on the cooling tower loop will control heat loss.

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Simultaneous Heating and Cooling in Dehumidification Systems (§ 6.5.2.3)
Most dehumidification in HVAC systems is provided naturally as a part of the cooling process. In the majority of applications in most climates, this uncontrolled, indirect dehumidification provides acceptable space humidity levels. However, to achieve lower humidity levels in some applications and in humid climates, active dehumidification is required, controlled by a space or duct humidistat. When conventional cooling systems are used for active dehumidification control, simultaneous heating and cooling is usually required: air is first cooled to below its dewpoint to remove moisture, then the air is heated so that the space served is not overcooled. To limit the energy used by these systems, the Standard allows humidistatic controls to cause simultaneous heating and cooling of the same airstream only if one or more of the following conditions apply:

- The system is capable of reducing supply air volume to 50% or less of the design airflow rate, or to the minimum ventilation rate specified in § 6.1.3 of ASHRAE *Standard 62-1999*, whichever is larger, before simultaneous heating and cooling takes place.
- The individual fan-cooling unit has a design cooling capacity of 80,000 Btu/h or less and is capable of unloading to 50% capacity before simultaneous heating and cooling takes place.
- The individual mechanical cooling unit has a design cooling capacity of 40,000 Btu/h or less.
- The systems serves spaces where specific humidity levels are required to satisfy process needs, such as computer rooms, museums, surgical suites, and buildings with refrigeration systems (supermarkets, refrigerated warehouses, ice arenas, etc.) for which fan volume controls as in Exception (a) are proved to the enforcement agency to be impractical. The last clause requires that the designer show that the system will not work well at airflow rates that are 50% or less of the design airflow rate. For instance, for a surgical suite, other codes may mandate a minimum circulation rate that requires a constant supply rate.
- At least 75% of the energy for reheating or for providing warm air in mixing systems is provided from a site-recovered (including condenser heat) or site-solar energy source. A good example of this exception is a standard dehumidifier that uses condenser heat to reheat supply air. A heat-pipe or plate heat exchanger that simultaneously reheats the air and precools outdoor air should also comply with this exception.
- Systems where the added heat to the airstream is the result of the use of a desiccant system and 75% of the heat added by the desiccant system is removed by a heat exchanger, either before or after the desiccant system, with energy recovery. This exception applies to standard desiccant dehumidifiers with a heat recovery wheel that uses exhaust air to precool the air that was heated and dried by the desiccant system. If the heat exchanger removes at least 75% of the heat that was added by the desiccant, then mechanical cooling may be used to further cool the air as required.

Humidification Systems (§ 6.5.2.4)
Humidification systems used in conjunction with outdoor air economizers can waste energy since the introduction of dry outdoor air in the winter adds to the humidification load. To minimize these losses, the Standard requires that systems that have both hydronic cooling and humidification systems designed to maintain inside humidity at greater than 35 °F dewpoint temperature must use a water

Example 6-ZZ—Two-Pipe Changeover System Requirements

Q

A two-pipe changeover system is proposed for a hotel. Each guest room will have a two-pipe fan coil with controls to change the control action of the thermostat based on water temperature. What is required for this system to meet § 6.5.2.2?

A

The following is an example of how this system might comply with § 6.5.2.2 and maintain guest comfort:

Small electric heating coils could be provided in each fan coil. This will provide heat in mild weather, allowing the two-pipe system to stay in the cooling mode until the outdoor air temperature drops sufficiently low that it can be assured no guest rooms require cooling. For instance, below 45°F, the system could operate in the heating mode. As the outdoor air temperature rises above 60°F, the system would switch to the cooling mode. A timer would be provided that would prevent a changeover from occurring if the outdoor air temperature changed from below 45°F to above 60°F in less than four hours.

Chilled water temperature would have to be reset based on outdoor air temperature, from, for example, 45°F at 60°F outdoor air temperature up to 60°F at 45°F outdoor air temperature. Similarly, the heating system would have to be reset from, for example, 170°F at 0°F down to 90°F at 45°F outdoor air temperature and further down to 75°F at 60°F outdoor air temperature.

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economizer if an economizer is required by § 6.3.1. Note that this requirement is limited to hydronic cooling systems; it does not apply to direct-expansion cooling systems. The reason is that hydronic systems are more readily fitted with a water economizer than direct-expansion systems.

Air System Design and Control (§ 6.5.3)

The subsections of § 6.5.3 apply to all air systems having a total fan system power greater than 5 HP. Fan system power is the sum of the nominal power demand (the nameplate horsepower) of all fans in a system that are required to operate at design conditions to supply air from the heating or cooling source (such as coils) to the conditioned spaces and return it back to the source or exhaust it to the outdoors. The following guidelines should be used to determine fan system power:

- One fan system is separate from another if they have different heat or cooling sources. For instance, if two air-handlers, each with separate supply fans and heating and cooling coils, supply a large ballroom, they are considered two separate systems even though they both serve the same room.
- Fans that ventilate only, such as garage exhaust fans or equipment room ventilation fans that transfer only unconditioned outdoor air, do not qualify as a fan system in this context. Fan systems must be part of a system with heating or cooling capability. (In any case, fans that only ventilate are unlikely to have any problems meeting the design requirements of this section since their pressure drops are typically very low.)
- Only fans that operate at "design conditions" need be included. For a heating-only fan system, only fans that operate at design heating conditions are included, and for cooling-only systems, only fans that operate at design cooling conditions are included. For systems that have both heating and cooling capability, the system would be rated by the higher of the power required at heating design conditions or cooling design conditions.
- Fans need to be included if they supply air from the heating or cooling source to the conditioned space, return the air from the space back to the source, or exhaust air from the conditioned space to the outdoors.

Fans that simply recirculate air locally (such as conference room exhaust fans) do not need to be included.

Examples 6-DDD through 6-III provide further clarification of fan system power issues.

Fan Power Limitation (§ 6.5.3.1)

Fans are one of the largest energy-using components of HVAC systems. However, regulating fan system design to improve performance is made difficult by the wide number of fan applications, from small fan coils serving a single zone to large central fan systems serving entire buildings. The Standard does not regulate small fan systems because most small air conditioners and fan coils are very limited in the external pressure they can overcome, so it is unlikely that designers are wasting significant amounts of fan energy by poorly designing air distribution systems. The fan power limits in § 6.5.3.1 are upper limits that only have a limiting impact on relatively large systems (systems that have significant fan system pressure drops).

The Standard limits the fan power in fan systems with a total nameplate horsepower greater than 5 hp. The limit is expressed in one of two ways: Option 1 specifies the maximum nameplate horsepower. This option is simple to apply but does not consider special filter requirements, heat recovery devices or other features that would increase the pressure drop across the fans and thus increase fan power. Option 2 specifies the limit in terms of maximum brake horsepower at the fan shaft and includes adjustments to account for special filtering or other devices.

With both options, the power limit applies to all fans that operate at peak design conditions, including primary supply fans, return fans, exhaust fans, and series type fan power VAV boxes. Parallel type van power VAV boxes typically do not operate at fan system design conditions and would not be included.

Option 1

With this option, a limit is placed on the fan system motor nameplate horsepower. The limit depends on whether the fan system is a constant volume fan or a variable volume fan system. The limit for constant volume fan systems is 0.0011 times the supply cfm. The limit for variable volume fan systems is 0.0015 times the supply volume (in CFM).

Constant volume systems (6-D)

$$hp_{max} = CFM_s \times 0.0011$$

Variable volume systems (6-E)

$$hp_{max} = CFM_s \times 0.0015$$

where

CFM_S = the maximum design supply airflow rate to conditioned spaces served by the system in cubic feet per minute

hp_{max} = the maximum combined motor nameplate horsepower

Option 2

With Option 2, the limit is placed on the brake horsepower at the fan shaft instead of the nameplate horsepower. This method is a little more complicated, but offers more flexibility for fan systems with special filtration requirements or other

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features that would increase static pressure.

The brake horsepower of the proposed design fan depends on the design air flow (CFM), the static pressure that the fan has to work against, and the efficiency of the fan. Since the limit is applied at the fan shaft, the efficiency of the motor or the variable speed drive are not considered. For a given fan, the brake horsepower at the shaft in IP units is given by the following equation:

(6-F)

$$bhp_i = \frac{CFM_i \times PD_i}{6356 \times \eta_i}$$

where

PD_i = the pressure drop across the i^{th} individual fan.

bhp_i = the brake horsepower of the i^{th} individual fan.

CFM_I = the airflow rate of the i^{th} fan at design conditions.

η_i = the efficiency of the i^{th} fan at design conditions

i = an index for a particular fan in the system.

The total brake horsepower for the entire fan system is the sum of the brake horsepower of each of the fans that operate at peak design conditions and is given be the following equation:

(6-G)

$$bhp_{Total} = \sum_{i=1}^{n} bhp_i$$

where

bhp_{Total} = the total brake horsepower for the fan system.

bhp_i = the brake horsepower of each individual fan.

n = the number of fans in the system that operate at design conditions

The maximum brake horsepower permitted by the standard is given by the following equations for constant volume and variable volume systems. The first part of the equation gives the basic allowance for brake horsepower. The second part of the equation gives additional brake horsepower for special filtration or devices listed in Table 6-F. The additional power for these devices is based on the CFM of air that flows through the device; not the total supply air CFM.

(6-H)

Constant volume systems

$$bhp_{max} = CFM_s \times 0.00094 + \sum \frac{CFM_i \times PD_j}{4131}$$

(6-I)

Variable volume systems

$$bhp_{max} = CFM_s \times 0.0013 + \sum \frac{CFM_i \times PD_j}{4131}$$

where

j = an index for a particular fan system feature that qualifies for additional

bhp_{max} = the maximum combined fan system brake horsepower.

CFM_S = the maximum design supply airflow rate to conditioned spaces served by the system in cubic feet per minute.

CFM_j = the design supply airflow rate through the j^{th} device, in cubic feet per minute.

PD_i = the additional pressure drop allowance for certain fan system features (see Table 6-F).

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Pressure Drop Adjustment Devices

This section provides a description of the types of devices that quality for additional fan power. See Table 6-F.

Fully ducted return and/or exhaust air systems. The basic brake horsepower allowance is based on the assumption that return air passes through an open plenum on its way back to the fan system. For systems where all the return air is ducted back to the return, an additional pressure drop allowance of 0.5 in. w.c. is allowed. This credit may not be applied for air systems that have a mixture of ducted and non-ducted return.

Return and/or exhaust airflow control devices. Some types of spaces such as laboratories, test rooms, or operating rooms require that an airflow control device be provided at both the supply air delivery point and at the exhaust. The exhaust airflow control device is typically modulated to maintain a negative or positive space pressure relative to surrounding spaces. An additional pressure drop and associated brake horsepower adjustment is permitted when this type of device is installed. The credit may be taken when some spaces served by an air handler have exhaust airflow devices and other spaces do not. However, the credit is taken only for the CFM of air that is delivered to spaces with a qualifying exhaust air flow device.

Exhaust filters, scrubbers, or other exhaust treatment. Some applications require that the air that leaves the building be filtered to remove dust or contaminants. Exhaust air filters are also associated with some types of heat recovery systems, such as run-around coils. In this application, the purpose of the filters is to help keep the coils clean which is necessary to maintain the efficiency of the heat recovery system. When such devices are specified and installed, the pressure drop of the device at fan system design condition may be included as a credit. When calculating the additional brake horsepower, only consider the volume of air that is passing through the device under fan system design conditions.

Table 6-F—Fan Power Limitation Pressure Drop Adjustments (Table 6.5.3.1.1.B)

Device	Adjustment
Credits	
Fully ducted return and/or exhaust air systems	0.5 in. w.c.
Return and/or exhaust airflow control devices	0.5 in. w.c
Exhaust filters, scrubbers, or other exhaust treatment	The pressure drop of device calculated at fan system design condition.
Particulate Filtration Credit: MERV 9 through 12	0.5 in. w.c.
Particulate Filtration Credit: MERV 13 through 15	0.9 in. w.c.
Particulate Filtration Credit: MERV 16 and greater and electronically enhanced filters	Pressure drop calculated at 2× clean filter pressure drop at fan system design condition
Carbon and other gas-phase air cleaners	Clean filter pressure drop at fan system design condition
Heat recovery device	Pressure drop of device at fan system design condition
Evaporative humidifier/cooler in series with another cooling coil	Pressure drop of device at fan system design condition
Sound Attenuation Section	0.15 in. w.c.
Deductions	
Fume Hood Exhaust Exception (required if 6.5.3.1.1 Exception (c) is taken)	-1.0 in. w.c.

--,,,

Particulate Filtration Credit: MERV 9 through 12 . The primary purpose of filters is to keep the fans, coils and ducts clean and to reduce maintenance costs. A secondary purpose is to improve indoor air quality.

Minimum Efficiency Reporting Value (MERV) ratings are used as the basis of this credit. This ratings indicates the amount of particulate removed from the air stream. A MERV rating is more efficient and removes more material. See ASHRAE Standard 52.2-1999 for details on MERV ratings.

For air handlers that have a MERV rating between 9 and 12, an additional pressure drop of 0.5 in. w.c. may be considered when calculating allowable brake horsepower for the fan system. The credit is calculated for just the CFM of air that actually passes through the filter, e.g. if just part of the air is filtered, then the credit applies just to this share.

Particulate Filtration Credit: MERV 13 through 15. Filters with MERV ratings between 13 asnd 15 provide 85% or greater filter effieicncy and these filters qualify for an additional 0.9 in. w.c. of pressure drop. Only consider the volume of air that passes througha the filter when calculating the additional brake horsepower allowance.

Particulate Filtration Credit: MERV 16 and greater and Electronically Enhanced Filters. The credit for filters with a MERV rating of 16 and greater and all electronically enhanced filters is based on two times the clean pressure drop of the filter at fan system design conditions. This clean pressure drop data is taken from manufacturers literature.

Carbon and Other Gas-Phase Air Cleaners. For carbon and other gas-phase air cleaners, additional brake horsepower is based on the rated clean pressure drop of the air

Example 6-AAA— Fan System Design Requirements, Constant Volume Hospital System with 100% Outside Air

Q

A constant volume air handler serving a hospital wing has a fan system design supply airflow of 10,000 cfm. The supply fan has a 20 hp (nameplate) supply fan motor which operates at a brake horsepower of 13.9 bhp. The exhaust fan has 5 hp motor which operates at a brake horsepower of 3.2 bhp. Flow control devices in the exhaust are used to maintain pressure relationships between spaces served by the system. The air handler uses MERV 13 filters, and exhaust air is completely ducted. The system uses 100 percent outside air and has a run-around heat recovery system with coils in the supply and exhaust air streams, each with 0.4 in. w.c. pressure drop at design airflow. Does this fan system comply with the fan power requirements in §6.5.3.1?

A

Even though this is a constant volume air handler, since it is a hospital and flow control devices are used at the exhaust of each space, the fan power requirements for a VAV system apply, per Exception 6.5.3.1.1 a. For this system, Option 2 is required in order to consider the additional pressure drop of the return air ducts, the MERV 13 filters and the heat recovery device. From Table 6.5.3.1.1 A, the allowable system brake horsepower for the system is:

$$\begin{aligned} \text{bhp} &= \text{CFM}_S \times 0.0013 + \text{A} \\ &= 10{,}000 \times 0.0013 + \text{A} = 13 + \text{A} \end{aligned}$$

From Table 6.5.3.1.1 B, the pressure drop adjustment for the MERV 13 filter is 0.9 in. w.c. and the pressure drop adjustment for the fully ducted return is 0.5 in. w.c. From manufacturers literature, the pressure drop adjustment for the heat recovery device is 0.4 in. w.c. The air flow through all of these devices is 10,000 CFM so the additional brake horsepower that is allowed is 5.33 bhp as calculated below.

$$\begin{aligned} \text{A} &= \frac{\text{CFM}_R \times \text{PD}_R + \text{CFM}_{M13} \times \text{PD}_{M13} + 2 \times (\text{CFM}_{HX} \times \text{PD}_{HX})}{4131} \\ &= \frac{10{,}000 \times 0.5 + 10{,}000 \times 0.9 + 2 \times (10{,}000 \times 0.4)}{4131} = 5.33 \text{ bhp} \end{aligned}$$

The total allowed bhp is 13.0 plus 5.33 or 18.33 bhp, which is greater than the fan system bhp of 17.1. Therefore, the system meets the requirements of the Standard.

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cleaning device at fan system design conditions.

Since the design brake horsepower is 3.2 + 0.6 = 3.8, which is lower than the allowed 7.35 bhp, this system would comply with the fan power requirements of the standard.

Heat Recovery Device. Heat recovery devices exchange heat between the outside air intake stream and the exhaust air stream. They are common for 100% outside air systems and in colder climates. There are two common types of heat recovery devices: heat wheels and run-around coils. Both increase the pressure and require a system with a larger brake horsepower.

Additional brake horsepower is based on the rated pressure drop of the air cleaning device at fan system design conditions.

Evaporative humidifier/cooler in series with another cooling coil. Additional pressure drop is allowed for systems that provide humidification or evaporative cooling in addition to conventional cooling coils.

Additional brake horsepower is based on the rated pressure drop of the air cleaning device at fan system design conditions.

Sound Attenuation Sections. Sound attenuation is needed to help isolate fan noise in many applications. The type of sound attenuation section that is credited by the standard is a passive system. A section of the duct is lined with sound attenuation materials that absorb noise, but increase friction. Active sound attenuation sections (noise cancelling devices) do not qualify for this section.

A credit equivalent to 0.15 in. w.c. is allowed for qualifying sound attenuation sections.

Example 6-CCC—Fan System Design Requirements, Laboratory Fume Hoods, Central Exhaust

Q

If the building in the previous example were served by a common exhaust fan instead of individual exhaust fans for each laboratory, would the system still comply with the standard?**A**Yes, Exception 6.5.3.1.1c still applies, except in this case, it can be applied to the entire exhaust, not just the Since the design brake horsepower is 3.2 + 0.6 = 3.8, which is lower than the allowed 7.35 bhp, this system would comply with the fan power requirements of the standard.

$$\text{bhp} = \text{CFM}_S \times \sum 0.0013 + \frac{\text{PD} \times \text{CFM}}{4131}$$

$$= 6{,}400 \times 0.0013 + \left(\frac{-1.0 \times 6{,}400}{4131} \right) = 6.77 \text{ bhp}$$

Since the design brake horsepower is 3.2 + 0.6 = 3.8, which is lower than the allowed 6.77 bhp, this system would comply with the fan power requirements of the standard.

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Hospital and Laboratory Systems (Exception 6.5.3.1.1a.)
Constant volume systems are common for hospitals and laboratories, however, in order to maintain pressure relationships between spaces in these types of buildngs, dampers or other airflow control devices are commonly used where air is exhausted from each space. If the space needs to be kept to a negative pressure, relative to its surroundings, in order to prevent the spread of contaminants, then the flow control device would be opened while flow control devices in surrounding spaces would be closed.

Constant volume systems that serve hospitals and laboratories that use flow control devices on exhaust and/or return to maintain space pressure relationships necessary for occupant health and safety or environmental control may use variable volume fan power limits.

Small Exhaust Fans (Exception 6.5.3.1.1b.)
Small exhaust fans with a motor nameplate rating less than 1 hp need not be included in the fan power for the proposed design, even though these fans may operate during fan system design conditions.

Fume Hood Exhaust (Exception 6.5.3.1.1c.)
In spaces with fume hoods (typically laboratories), fan energy associated with the fume hoods mayk be excluded from the fan power in the proposed design, however, there are some restrictions.

- Only Option 2 may be used.
- This exception may not be combined with any of the other exhaust side credits in Table 6.5.3.1.1B, including return or exhaust airflow control devices and exhaust filters and/or scrubbers. The exception can, however, be combined with return air ducts and heat recovery, even though heat recovery is installed at the air exhaust.

Example 6-DDD—Calculation of Fan Energy, Fan-Coil System

Q

A building HVAC system consists of 40 fan coils serving individual zones, each with 1/3 hp motors. Does this system need to comply with § 6.5.3.1?

A

No. Each fan coil is a separate fan system because each has a separate cooling and heating source. The total fan system power for each fan system is only 1/3 hp, so the systems are exempt from meeting the requirements of § 6.5.3.

Example 6-EEE—Adjustment of Fan Energy, Electronically Enhanced Filter

Q

A 20,000 cfm supply fan system includes an electronically enhanced filter assembly with a clean pressure drop of 1.25 in. w.c. Using Option 2, how much additional fan bhp is allowed for this filter?

A

For this type of filter Table 6.5.3.1.1B allows the rated pressure drop for additional brake horsepower to be two times the rated clean pressure drop of the of the filter . The additional fan power (bhp) is determined as:

$$\text{bhp} = \frac{\text{CFM}_{\text{filter}} \times 2 \times \text{PD}_{\text{filter}}}{4131}$$

$$= \frac{20000 \times 2 \times 1.25}{4131} = 12.1 \text{ bhp}$$

Example 6-FFF—Fan System Design Requirements, VAV Changeover System

Q

What are the fan system design requirements for a variable air volume changeover system (also called a variable volume and temperature system) that includes a bypass damper at the fan?

A

This system is variable volume at the zone level, but the bypass damper will maintain a relatively constant airflow through the fan. The system is therefore a constant volume system in this context, and it must meet the fan power requirements in Table 6.5.3.1.1A for constant volume systems.

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- A negative pressure drop adjustment of 1 in. w.c. shall be taken. This means that the allowed brake horsepower of the fans (excluding the fume hoods) is reduced.

- This credit may be combined with Exception 6.5.3.1.1a., e.g. the the power limits of a VAV system may be used for constant volume systems in hospitals and laboratories when exhaust airflow devices are used. While for exhaust airflow devices may not be credited in combination with this exception, the devices can qualify the constant volume system to use the limits for a VAV system.

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Example 6-GGG— Fan System Design Requirements, VAV Reheat System in Office

Q

A VAV-reheat system serves a low-rise office building. The building is served by one variable air volume packaged rooftop unit with a 10 hp supply fan with a variable speed drive. Four parallel fan-powered VAV terminal units are used on north facing perimeter offices for heating. Two series fan-powered VAV boxes, each with a 1/3 horsepower fan with ECM motor, serve two interior conference rooms. The space also uses a local exhaust fan for each of the four bathrooms. Fans for the system are listed below. Fan performance is as described in the table below. Is this system in compliance with § 6.5.3.1?

Quantity	*Fan Service*	*Design CFM, Each*	*Brake HP*	*Nameplate Motor Horsepower*
1	Supply fan, with variable-speed drive	12,000	8.7	10
2	Condenser fans	9,300	0.7	1.0
1	Return fan	11,000	4.2	5.0
4	Bathroom exhaust fans	350	0.16	0.2
4	Parallel fan-powered VAV boxes	400	0.08	1/5
2	Series fan-powered VAV boxes	600	0.12	1/3

A

The fan system can comply with either the nameplate horse power limitation or the brake horsepower limitation. The nameplate horsepower will be checked in this example. First, determine which fans to include in the nameplate fan system power calculation: The supply and return fans are clearly included the fan power calculation. The condenser fans are not included, since they circulate outdoor air and do not affect the conditioned air supplied to the space. The toilet exhaust fans are not included since they qualify for exception (b) of 6.5.3.1.1, which exempts individual exhaust fans with nameplate horsepower of 1 hp or less. The parallel fan-powered VAV boxes are not included in the fan power calculation since they operate in heating mode, when the supply fan is not operating at design conditions. The series fan-powered boxes run continuously, and are included in the fan power calculation. The total nameplate horsepower is 15.67 bhp, as shown below.

$$\text{hp} = 10 + 5 + 2 \times 1/3 = 15.67 \text{ hp}$$

The total supply air delivered from the air handler is 12,000 cfm, and the allowed nameplate horsepower for a variable air volume system is 18 hp as shown below.

$$\text{hp}_{\text{Max}} = 12{,}000 \times .0015 = 18 \text{ hp}$$

The total nameplate horsepower of 15.67 hp is less than the allowed 18 hp, so the fan system complies with the standard. If the nameplate horsepower exceeded the allowable limit, the system brake horsepower could be checked for compliance.

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Exahmple 6-HHH—Fan Power Calculation, VAV System

Q

A conventional VAV system serves an office building. Fan performance is as described in the table below. Is the system in compliance with § 6.5.3.1?

Quantity	*Fan Service*	*Design CFM, Each*	*Brake HP*	*Nameplate Motor Horsepower*
2	Supply fans with variable-speed drives	75,000	70.5	75 high efficiency
4	Economizer relief fans	32,000	3.5	5
1	Toilet exhaust	6,750	2.7	3 high efficiency
1	Elevator machine room exhaust fan	5,000	Unknown	¾
2	Cooling tower exhaust fans	unknown	Unknown	15
15	Conference room exhaust fans	500	240 watts	—
120	Series type fan-powered mixing boxes	1,300 (average)	Unknown	⅓

A

First, determine which fans to include in the fan power calculation:

- The supply fans are clearly included.
- The economizer relief fans are not included because they will not operate at peak cooling design conditions. (Had return fans been used, they would have to be included in the calculation.) Since the relief fans are not counted as part of the system fan power, the relief fan credit in Equation 6-**Error! Reference source not found.** is zero.
- The toilet exhaust fan is included since it exhausts conditioned air from the building rather than having it returned to the supply fan and it operates at peak cooling conditions.
- The elevator exhaust fan is not part of the system since, it is assumed in this case, the makeup air to the elevator room is from the outdoors rather than from the building. Had makeup air been transferred from the conditioned space, the fan would have been included.
- The cooling tower fans operate at design conditions, but they also are not part of the system because they circulate only outdoor air.
- The conference room exhaust fans are assumed to be transfer fans; they simply exhaust air from the room and discharge it to the ceiling plenum. Since this air is not exhausted to the outdoors, the fans are not included.
- The series type fan-powered VAV boxes are included since they assist in supplying air to the conditioned space and operate at design cooling conditions. If the boxes were the parallel type, they would not be included since they would not operate at design cooling conditions.

Second, using Option 1, add up the nameplate horsepower (*not* brake horsepower) of the eligible fans. For this example, the fans that are included and their motor power requirements are:

Fan Service	Quantity	Motor HP each	Total HP
Supply fans	2	75	150
Toilet exhaust fan	1	3	3
Fan powered VAV boxes	120	⅓	40
Total Fan System Power			193

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Example 6-HHH—Fan Power Calculation, VAV System *[continued]*

Third, determine the supply air rate. This is the total airflow rate supplied through the heating or cooling source, which in this case is equal to the total of the two supply fan airflow rates, 2 x 75,000 = 150,000 cfm. The supply rate is not the total of the fan-powered VAV box airflow rates; although this is the ultimate supply air rate to the conditioned space, this entire airflow does not flow through the heating or cooling source. The airflow rate from the exhaust fan is also not included in the supply air rate for the same reason.

Fourth, determine the criteria from Table 6.5.3.1.1A. The series fan-powered VAV boxes supply a constant flow of air to the conditioned space, but the primary airflow—the airflow through the cooling source—varies as a function of load, so this system meets the definition of a VAV system. Using Option 1, the maximum nameplate horsepower for the system is 225 hp as shown below.

$$\text{hp} = \text{CFM}_S \times 0.0015$$
$$= 150{,}000 \times 0.0015 = 225 \text{ hp}$$

Fifth, compare the allowable fan system power with the proposed power The actual fan system nameplate horsepower of 193 hp is less than the 225 hp limit, so this system complies. If the system did not comply, the designer could consider using larger ducts to reduce static pressure or shifting to parallel fan-powered VAV boxes.

Example 6-III—Calculation of Fan Power Energy, Floor-by-Floor System

Q

A high-rise building has floor-by-floor supply air-handling units but central toilet exhaust fans and minimum ventilation supply fans. How is the Standard applied to this system?

A

Each air-handler counts as a fan system. The energy of the central toilet exhaust and ventilation fans must be allocated to each air-handler on a cfm-weighted basis. For instance, if one floor receives 2,000 cfm of outdoor air and the outdoor air fan supplies a total of 10,000 cfm with a 5 hp motor, 20% (2,000/10,000) of the fan hp (1 hp) is added to the fan power for the floor's fan system. Note that the airflow rates from the exhaust and ventilation fans are not included in the supply rate calculation since these rates do not add to the airflow going through the heating/cooling coils in the floor-by-floor air-handlers; see also Example 6-**Error! Reference source not found.**.

Example 6-JJJ—Part-Load VAV Fan System Efficiency, Size Limit

Q

A VAV fan system includes a 25 hp supply fan and a 7.5 hp return fan. Does it have to meet the 30% kW at 50% cfm requirement?

A

The 25 hp supply fan has to meet the requirement while the 7.5 hp return fan does not have to. The 10 hp limit applies to each individual fan.

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Variable Air Volume Fan Control (§ 6.5.3.2)

Individual VAV fans with motors 10 hp (7.5 kW) and larger must have one of the following forms of controls:

- A mechanical or electrical variable speed drive
- Variable pitched blades (if the fan is a vane-axial), or
- Other controls and devices that will result in fan motor demand of no more than 30% of design wattage at 50% of design air volume when static pressure setpoint equals one-third of the total design static pressure, based on manufacturer's certified fan data.

Figure 6-V shows generic part-load performance curves for several fan types and static pressure control systems. It is based on typical fan selections with static pressure setpoints equal to one-third of the total system static pressure. Actual fan performance will depend on fan selection, the location of the static pressure sensor, and the control setpoint. The curves indicate that only fans with variable speed drives and vane-axial fans meet the 30% power at 50% cfm requirement. In most cases, fans with inlet guide vanes and discharge dampers will not meet this requirement.

In addition to their energy efficiency, variable-speed drives will also reduce noise levels at part load, compared to inlet vanes and discharge dampers, which increase noise at part load. Variable-speed drives will also allow airfoil fans to be operated down to very low flow rates.

Other systems, such as centrifugal plug fans with variable inlet cones or scroll dampers, *may* meet the 30%/50% performance requirement, but manufacturer's certified fan data must be provided to the authority having jurisdiction to justify the claim.

Example 6-JJJ—Part-Load VAV Fan System Efficiency, Certified Tests

Q

A VAV fan system has a new static pressure control device. The manufacturer's sales brochure shows a generic part-load performance curve that indicates the device meets the 30% kW at 50% cfm requirement. May this device be used to meet § 6.5.3.2.1?

A

Not without more complete documentation. Sales literature is often exaggerated and does not constitute the "certified" performance required by this section. To meet the Standard, the manufacturer would have to do a laboratory or controlled field experiment using the device in a typical application (e.g., typical static pressure required for a VAV system, typical fan selection for this duty, etc.).

The fan power would be measured at a design airflow rate. The airflow rate would then be reduced (e.g., with dampers) to 50% of the design rate and the device allowed to modulate as required to maintain the duct static (located in the simulated system in accord with § 6.5.3.2.2) at one-third of the total design static pressure. The power measured at this condition is divided by the power measured at design airflow rate. The ratio must be 30% or less to comply. The manufacturer would document the test, then write and sign a letter stating that the tests were done accurately in a manner consistent with the intent of the Standard, and that the device met the 30%/50% criterion.

Example 6-KKK—Zone Static Pressure Reset

Q

A VAV system has zone-level direct digital controls. The VAV damper is controlled by a floating control system, meaning the damper is driven open or driven closed by two binary outputs. The actual damper position is not known with this system, so static pressure setpoint reset by zone damper position in accord with § 6.5.3.2.3 does not appear to be possible. Does this system comply with the Standard, and if not, how can it be redesigned to comply?

A

Static pressure setpoint reset off the VAV damper position is required if the system has DDC at the zone level, regardless of the type of VAV damper control used. To comply with § 6.5.3.2.3, this system must be modified to provide this control. Possible modifications include:

- Adding a feedback analog input to the zone controller indicating VAV damper position.
- Changing the control from floating control to analog output control and using the analog output signal to indicate damper position.
- Adding timers in software to measure how long the damper is pulsed open and pulse closed. This information can be used to estimate damper position. Occasional zeroing of the damper position is required for reliable performance.

The third option above is the most common and least expensive option.

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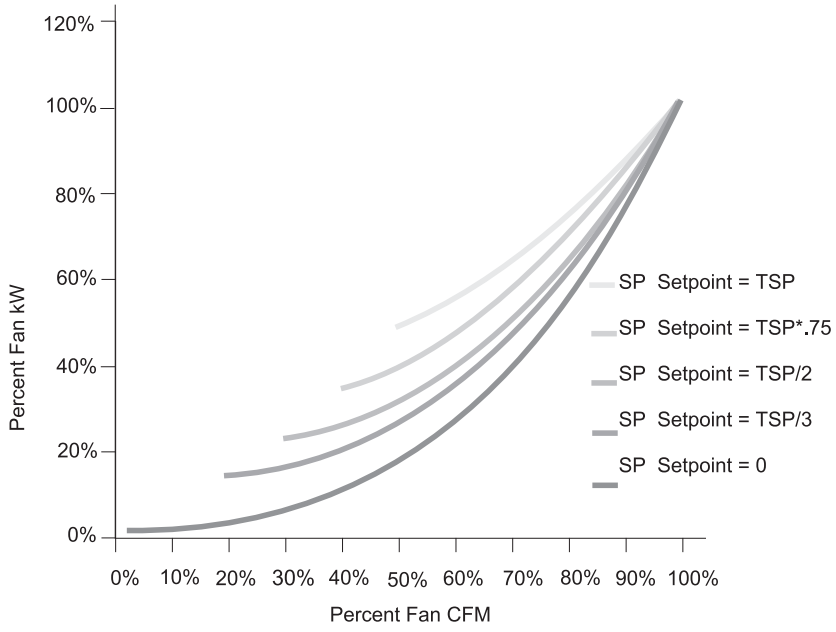

Figure 6-U—Part-Load Curves for Variable-Speed Drive Fan at Various Setpoints

Static Pressure Sensor Location (§ 6.5.3.2.2)
Static pressure sensors used to control variable air volume fans must be positioned so that the controller setpoint is no greater than one-third the total design fan static pressure. If this results in the sensor being located downstream of major duct splits, multiple sensors must be installed in each major branch to ensure that static pressure can be maintained in each branch.

Direct digital control systems with zone reset capability meeting the requirements of § 6.5.3.2.3 are exempt from this requirement. The static pressure sensor for such systems may be situated in any location, including at the fan discharge. This is because the setpoint is reset based on actual VAV box demand, so the location and setpoint have no impact on performance. In fact, a pressure sensor is not even required. However, to make the control system design more flexible and more stable, it is best to locate the sensor according to § 6.5.3.2.2 even though it is not required.

Static Pressure Setpoint Reset (§ 6.5.3.2.3)
Figure 6-U shows the performance of a fan with a variable-speed drive at various static pressure setpoints. The lower the setpoint, the more efficient the system. The lowest curve shows the ideal performance where static pressure is reset based on the zone requiring the most pressure, i.e., the setpoint is reset lower until one zone damper is nearly wide open. Because of the improved performance of this control sequence, the Standard requires it to be implemented for systems that have direct digital control (DDC) of individual zone boxes that are capable of reporting zone information to the central control panel controlling the air-handler.

Hydronic System Design and Control (§ 6.5.4)

The requirements of § 6.5.4 apply to pumping systems with total pump system power larger than 10 hp. Pump system power is the sum of the motor nameplate horsepower of all pumps that are required to operate at design conditions to supply fluid from the heating or cooling source to all heat transfer devices (e.g., coils, heat exchanger) and return it to the source.

Variable Flow Requirement (§ 6.5.4.1)
The Standard requires that pumping systems with modulating or two-position controls must be designed for variable flow. The system must be able to operate down to 50% of design flow or lower. This means that two-way rather than three-way control valves must be used.

Individual pumps serving variable flow systems having a pump head exceeding 100 ft and a motor exceeding 50 hp must have variable speed drives (or similar devices) that will result in pump motor demand of no more than 30% of design power at 50% of design water flow. The controls or devices must be controlled to maintain a desired flow or to maintain a

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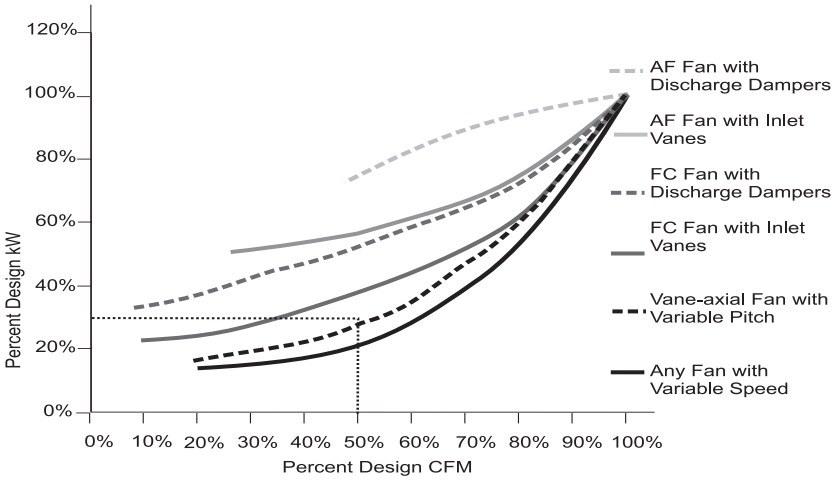

Figure 6-V—Generic Part-Load Curves for a Variety of Fans

minimum required differential pressure. In the latter case, differential pressure must be measured at or near the most remote heat exchanger or the heat exchanger requiring the greatest differential pressure. This remote location will ensure that the differential setpoint is as low as possible; as with fans (see Figure 6-U), the lower the setpoint, the greater pump energy savings will be.

The following exceptions to § 6.5.4.1 apply:

- Systems where the minimum flow (50% of design flow) is less than the minimum flow required by the equipment manufacturer for the proper operation of equipment served by the system, such as chillers, and where total pump system power is 75 hp (60 kW) or less. This exception is limited, in general, to single chiller systems (see Example 6-MMM).
- Systems that include no more than three control valves.

The Standard does not require any specific type of pump flow or pressure control. Pumps that simply "ride their pump curves"—those that are not controlled at all—will still use less energy at low flows than at design flow. However, the higher pressures that occur at low flow may exceed control valve differential pressure ratings and cause flow rates to exceed those desired. Energy use can be reduced and differential pressures can be better controlled by using multi-speed motors, staged pumps, or, ideally, variable-speed drives.

Some variable flow systems, such as chilled water systems and some hot water systems, will require that a constant flow rate, or at least a minimum flow rate, be maintained through the primary cooling/heating equipment (chiller, boiler). In this case, a primary-secondary system (Figure 6-X) is commonly used. Improvements in chiller controls, which are now more tolerant of variable chiller flow, also allow the use of primary-only variable flow chilled water plants, as shown in Figure 6-W. The conventional primary-secondary system still offers significant advantages in control simplicity, but it costs more to install and operate compared to a primary-only system with variable-speed drives.

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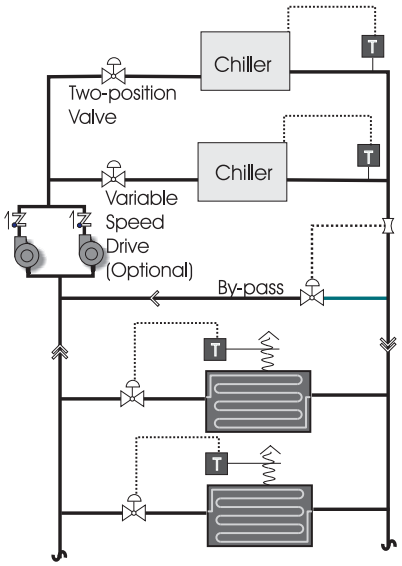

Figure 6-W—Primary-Only Chiller Plant

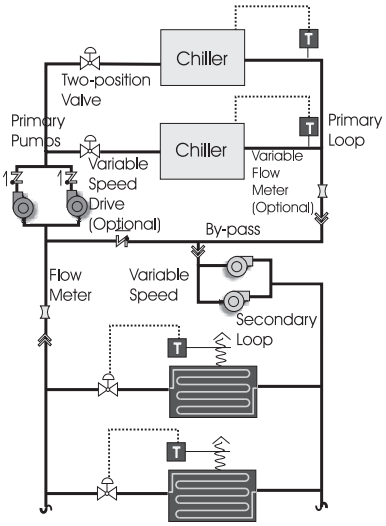

Figure 6-X—Primary-Secondary Chiller Plant

Example 6-LLL—Variable Flow Hydronic System

Q

A hot water system has two-way valves at most coils, but occasional three-way valves are provided at the end of branches to ensure flow through them. Does this design comply with the Standard?

A

Yes, provided the total flow through three-way valves does not exceed 50% of design flow. While these end-of-line valves are allowed, they are not usually required except perhaps in very large campus systems. Water piping is generally designed for water velocities that are high enough so that the time it takes for chilled or hot water to leave the plant and reach the control valve will be seconds or minutes, a small enough time that the system will not be "starved" and no discomfort will result. To minimize energy use in variable flow systems, limit the use of three-way valves to one or two to prevent pump dead heading.

Example 6-MMM—Variable Flow in Multi-Chiller Plants

Q

A chiller plant has two chillers piped in parallel with primary-only pumping. Each chiller is sized for 50% of the load and each has a minimum flow rate that is above 50% of the design flow rate through the chiller. Can this system be designed for constant flow via Exception (a) to § 6.5.4.1?

A

No. The "design flow" is the overall system flow, not the flow through each individual chiller. In this case, 50% of the design flow is sufficient to keep one chiller on line. The system could allow the chillers to be staged with the load so that one chiller could remain on-line at 50% of design system flow. The system must be designed for variable flow.

Exception (a) to § 6.5.4.1 really only exempts single-chiller (or boiler) systems from the variable flow requirement, and even then only if they cannot operate with 50% of the design flow.

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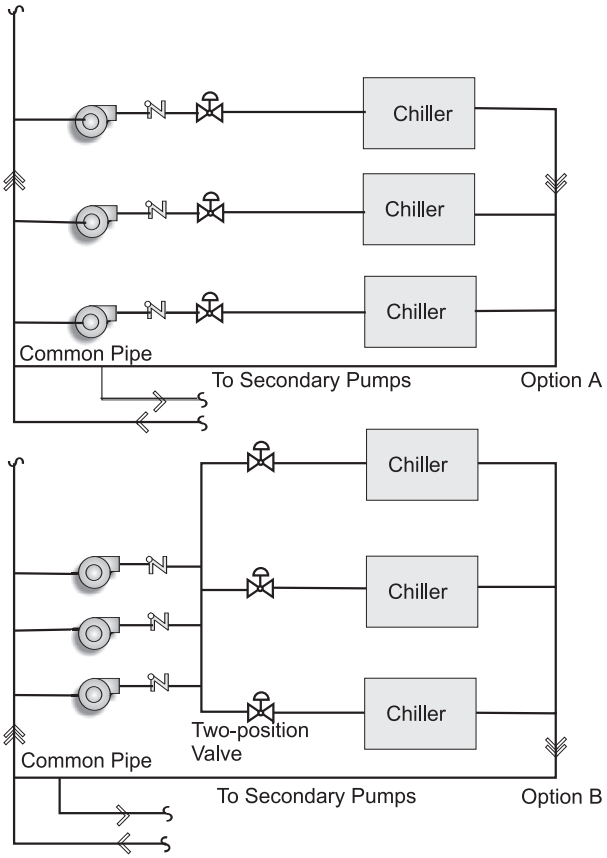

Figure 6-Y—Pumping Arrangements

Pump Isolation (§ 6.5.4.2)
When a chilled water plant includes more than one chiller, the system must be designed so that the flow in the chiller plant can be automatically reduced, correspondingly, when a chiller is shut down. (Chillers piped in series for the purpose of increased temperature differential may be considered as one chiller.) Similarly, when a boiler plant includes more than one boiler, the system must be designed so that the flow in the boiler plant can be automatically reduced, correspondingly, when a boiler is shut down.

Section 6.5.4.2 essentially requires that flow through chillers (or boilers), when piped in parallel, must be shutoff when the chillers (or boilers) are inactive. The two most common ways to do this are shown in Figure 6-Y for a typical multi-chiller plant. Option A at top of the figure shows a dedicated pumping arrangement (shown in the figure with optional manual valves to allow one pump to serve another chiller in case of multiple equipment failure). Option B at the bottom of the figure shows headered pumps with automatic isolation valves at each chiller.

Chilled and Hot Water Temperature Reset Controls (§ 6.5.4.3)
Resetting primary chilled water or hot water temperatures at part load improves the efficiency of the primary equipment and reduces energy losses through piping. Section 6.5.4.3 therefore requires that chilled and hot water systems with a design capacity exceeding 300,000 Btu/h supplying chilled water or hot water to comfort conditioning systems must include controls that automatically reset supply water temperatures upward (for cooling systems) or downward (for heating systems) at low loads. Reset may be based on any of the following:

- *Actual system demand, i.e., the cooling or heating coil that requires the coldest (cooling systems) or warmest (heating systems) water*: In other words, supply water temperature is reset so that the coil control valve that is the farthest open is maintained nearly wide open. This strategy is both the most energy efficient and the most reliable at ensuring no coil is starved. However, it is only practical if there are very few coils served by the system or if all coils are controlled by a direct digital control system that can communicate with the chiller or boiler control systems.
- *Building load indicators such as return water temperature*: This signal should be used with caution, however, since it provides only an indication of average system requirements. For instance, if one coil is at near design conditions while all others are at low load, this strategy would starve the first coil and comfort levels in the space it served would not be maintained. This strategy also does not work well if coils are used for dehumidification since colder supply water may be required even at low loads.
- *Outdoor air temperature*: This strategy works well for heating systems since space loads are almost proportional to the difference between inside and outside

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temperatures. Aggressive reset using this strategy will usually not be reliable for cooling systems because the majority of space-cooling loads are independent of outdoor air temperature.

The Standard does not address how much reset must occur. This is left up to the designer (See Example 6-NNN). The following exceptions to § 6.5.4.3 apply:

- *Where the supply temperature reset controls cannot be implemented without causing improper operation of heating, cooling, humidification, or dehumidification systems*: Examples include systems requiring maximum dehumidification capability at all times of the year.
- *Hydronic systems (such as those required by § 6.5.4.1) that use variable flow to reduce pumping energy*: For such systems, the use of supply water temperature reset will reduce the pumping energy saved by the variable flow design. Note that doing both variable flow and reset is possible, but the energy savings will not be cumulative. The optimum amount of reset that will minimize pumping energy and system losses while maximizing primary equipment efficiency is very complex and must be determined using a detailed analysis (see Chapter 11).

Hydronic (Water-Loop) Heat Pump Systems (§ 6.5.4.4)

For heat pump loops with total pump system power exceeding 10 hp, two-position valves at each hydronic heat pump must be provided and interlocked to shutoff water flow to the heat pump when the compressor is off. This basically converts the system into a variable flow system. As such, these systems also must comply with § 6.5.4.1.

Heat Rejection Equipment (§ 6.5.5)

This section applies to heat rejection equipment used in comfort cooling systems such as air-cooled condensers, open cooling towers, closed-circuit cooling towers, and evaporative condensers. It does not apply to heat rejection devices, such as air-cooled condensers, included in the energy ratings for equipment listed in Tables 6.8.1A through 6.8.1D in the Standard.

Each fan powered by a motor of 7.5 hp or larger must have the capability to operate at two-thirds of full speed or less. Fan controls must be provided that automatically change the fan speed to control the leaving fluid temperature or condensing temperature/pressure of the heat rejection device.

Figure 6-Z shows the performance of a cooling tower with single-speed, variable-speed, and two types of two-speed motors. It is clear that the multi-speed motors reduce energy costs significantly over single-speed fans. The best control is achieved with a variable-speed drive, but two-speed motors come very close. The following exceptions to § 6.3.5 apply:

- Condenser fans serving multiple refrigerant circuits.
- Condenser fans serving flooded condensers.
- Installations located in climate zones 1 and 2. In these climates, heat rejection fans tend to operate at high speed most of the time so speed controls may not be cost-effective.
- Up to one-third of the fans on a condenser or tower with multiple fans where the lead fans comply with the speed control requirement. In other words, for a three-cell cooling tower, one of the fans may be single speed.

Example 6-NNN—Reset Requirements, Boiler Reset on Outdoor Air

Q

A gas-fired boiler designed for 180°F water temperature under peak conditions includes a controller that resets the boiler hot water setpoint proportional to outdoor air temperature. In order to prevent flue gas condensation on the tubes and flue, hot water temperatures may not be reset as aggressively as they might be if a mixing valve were used. Does this design comply?

A

Yes. The Standard does not establish how much reset is required. To prevent flue gas condensation, supply water temperatures should not fall below about 130°F or so, depending on the boiler. The reset schedule for this system might be to provide 180°F water during cold weather and 130°F water during mild weather. Designs that use a mixing valve can provide even lower supply water temperatures as delivered to the coils. However, these systems should also include a boiler-reset controller to improve boiler efficiency by reducing stack and casing losses.

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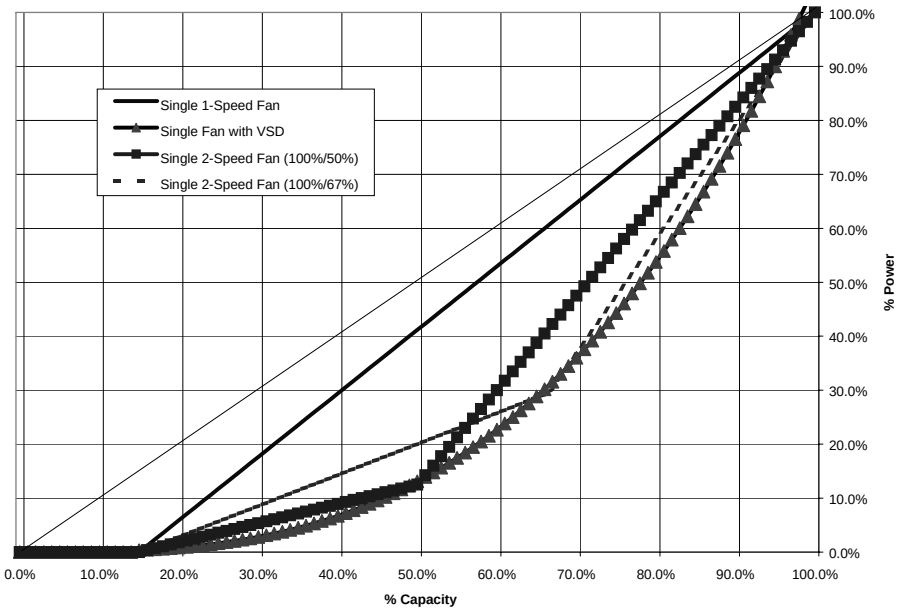

Figure 6-Z—Cooling Tower Fan Control Performance

Energy Recovery (§ 6.5.6)

Exhaust Air Energy Recovery (§ 6.5.6.1)

The Standard requires exhaust air energy recovery when both of the following conditions are met: an individual fan system has a design supply air of greater than or equal to 5,000 cfm AND a minimum outdoor air supply of greater than or equal to 70% of the design supply air. Equipment used to meet this requirement includes plate heat exchangers (plastic and metal), heat-pipes, run-around coils, and enthalpy wheels.

The Standard defines exhaust air energy recovery as the process of exchanging heat (sensible and/or latent) between the exhaust and outdoor airstreams. This reduces energy usage in the following manners:

- During periods of heating, the exhaust air can preheat the cool outdoor air through sensible (dry) exchange.
- During periods of cooling, the exhaust air can precool the hot outdoor air through sensible (dry) exchange.
- During periods of cooling, dry exhaust air can be used to dehumidify moist outdoor air through latent exchange.
- During periods of heating, exhaust air can be used to humidify dry outdoor air through latent exchange.

This requirement will generally apply to two applications: central 100% outdoor air supply systems and systems serving laboratories and institutional occupancies (such as schools, prisons, and theaters) where there is a high minimum requirement for ventilation air.

Where required, the exhaust air energy recovery system must have a minimum 50% recovery effectiveness. This recovery effectiveness must be demonstrated in either the heating or cooling mode. The recovery effectiveness, E, is defined as:

$$E = \frac{h_{OA\_entering} - h_{OA\_leaving}}{h_{OA\_entering} - h_{RA}} \geq 50\% \qquad \text{(6-J)}$$

$h_{OA\_entering}$ = the enthalpy of the outdoor air entering the exhaust air recovery system (Btu/lb dry air). Alternatively described as "Supply Air Entering," "Entering Supply Air", and Station 1 or X_1."

$h_{OA\_leaving}$ = the enthalpy of the outdoor air leaving the exhaust air recovery system (Btu/lb dry air). Alternatively described as "Supply Air Leaving," "Leaving Supply Air", and Station 2 or X_2."

h_{RA} = the enthalpy of the return air entering the exhaust air recovery system (Btu/lb dry air). Alternatively described as "Exhaust Air Entering," "Entering Exhaust Air", and Station 3 or X_3."

When outdoor air load is sensible (heating only, no humidification for example), the above equation is still correct (the enthalpy differences between the airstreams will be comprised of sensible heat only). For simplicity in these cases, the designer may replace enthalpy with dry-bulb temperature to calculate recovery effectiveness.

Note that Equation (6-A) differs from those in the handbook and standards in that there are no terms for mass flow, such as those in Equation (6-K).

$$E = \frac{m_s\left(h_{OA\_entering} - h_{OA\_leaving}\right)}{m_{min}\left(h_{OA\_entering} - h_{RA}\right)} \geq 50\% \qquad \text{(6-K)}$$

m_s = mass flow of the supply air.

m_{min} = mass flow of the minimum flow.

This is because the performance of the air-to-air heat exchanger is defined in the component standards as the exhaust air

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effectiveness. Performance in extracting energy from the exhaust airstream always improves as the airflow imbalances in favor of the supply. The effectiveness of the heat exchanger in extracting heat from the exhaust increases. To determine energy exchanged the exhaust air effectiveness number is applied to the exhaust airstream with its lower mass flow. In the case of building energy use, we are interested in the supply air effectiveness. Any additional supply airflow must still be heated, humidified, cooled and/or dehumidified (it then exits the building through other pathways with an energy recovery effectiveness of 0%). The form of the equation without the mass flow terms captures the recovered energy in the supply air and compares it to the energy required to condition that air to the return/exhaust air conditions. This supply air effectiveness accurately characterizes the performance of the heat exchanger in the building energy system.

When energy recovery is applied, it is important to reduce the design loads on the system accordingly. Heating and cooling equipment should be selected ("downsized or right sized") based on the new design loads with energy recovery.

Exhaust air energy recovery systems must be installed with bypass or other controls to permit air-economizer operation where economizers are prescribed in § 6.5.1.1. For instance, additional outdoor air intake dampers may be provided that bring air directly into the supply air system without going through the heat exchanger. This keeps the energy recovery system from preheating the outdoor air when the economizer is operating. For variable volume systems, providing a bypass will also reduce fan energy by reducing pressure drop. There are a number of exceptions to the requirement for exhaust air energy recovery systems:

- Laboratory systems that meet the requirements of fume hoods in § 6.5.7.2. This includes applications of variable volume fume exhaust systems that reduce design outdoor airflow to 50% or less and direct (auxiliary) makeup air systems that provide 75% or more of the exhaust air with tempered air.
- Systems serving buildings that are heated only and controlled to 60°F or less (typically warehouses).
- Systems exhausting toxic, flammable, paint or corrosive fumes, or dust. Energy recovery on these fume streams could be costly or unsafe.
- Commercial kitchen hoods used for collecting and removing grease vapors and smoke. The grease precipitation would likely render any heat exchanger useless and would be a fire hazard as it would be very difficult to clean.
- Where more than 60% of the outdoor air heating energy is provided by site-recovered or site-solar energy. Strategies to do this are described next.
- Heating systems in climate zones 1–3 (see Appendix D for climate data). Heating-only systems can be exempted by this requirement. Heating and cooling systems in mild climates may be exempted if they meet both this heating system exception and the cooling system exception that follows.
- Cooling systems in climates with a 1% cooling design wet-bulb temperature less than 65°F (see Appendix D for climate data). Cooling-only systems can be exempted by this requirement. Heating and cooling systems in mild climates may be exempted if they meet both this cooling system exception and the heating system exception immediately above.
- Where the largest single exhaust source is less than 75% of the design outdoor airflow. This exception is provided to account for the impracticality of recovering heat from multiple exhaust sources for a single outdoor air intake. An example could be a high-rise residential facility with a single pressurized outdoor airshaft but a half-dozen toilet and kitchen exhaust risers.
- Systems requiring dehumidification that employ energy recovery in series with the cooling coil. This exception recognizes the energy savings inherent in series energy recovery when employed in dehumidification systems.

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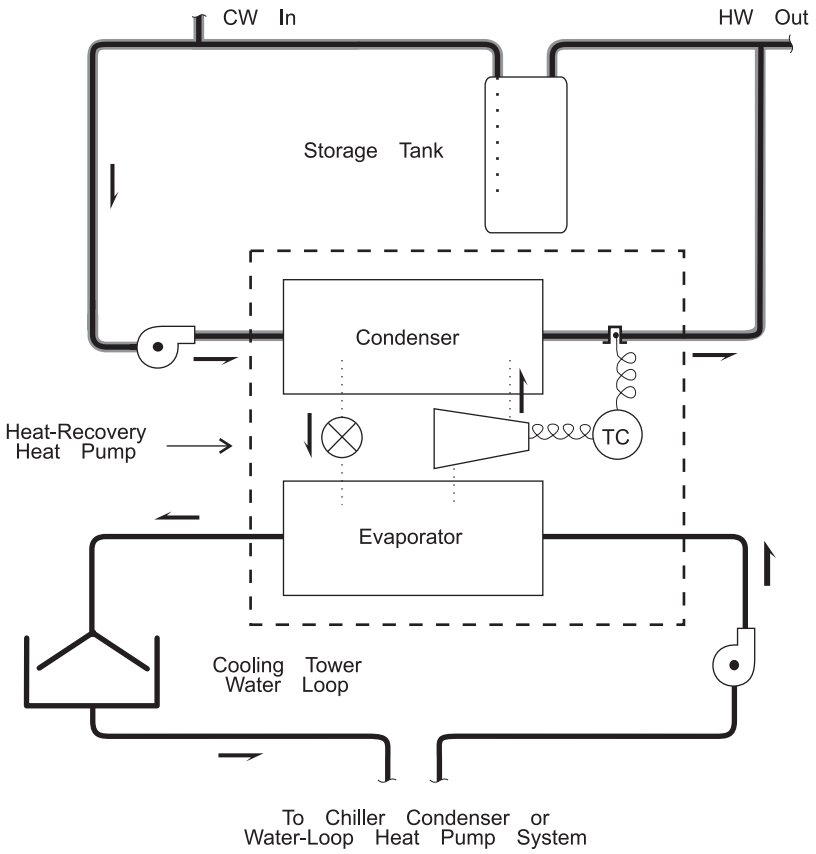

Figure 6-AA—Service Water Heating with Heat-Recovery Heat Pump

Heat Recovery for Service Water Heating (§ 6.5.6.2)

The Standard requires heat recovery from the condenser side of water-cooled systems for preheating service hot water in large 24-hour facilities. Heat recovery is most effective where the water heating loads are large and well distributed throughout the day. Typical applications are hotels, dormitories, mixed-use retail/residential projects, commercial kitchens, and institutions such as prisons and hospitals. A facility must comply with this heat recovery requirement if all of the following are true:

- The facility operates 24 hours a day.
- The total installed heat rejection capacity of the water-cooled system exceeds 6,000,000 Btu/h. This equates to roughly 400 tons of electric chiller capacity or 250-330 tons of gas- or thermally fired chiller capacity.
- The design service water-heating load exceeds 1,000,000 Btu/h. This equates to a 1,000-bed nursing home (at 1.5 gallon per hour per bed) or a 75-room hotel.

Where required, the heat recovery system must meet the smaller of two conditions:

- Sixty percent of the peak heat rejection load at design conditions. For example, if the chiller plant were designed to reject 2,000,000 Btu/h at design conditions, the heat recovery system must be designed to recover 1,200,000 Btu/h.
- Preheating of the peak service hot water draw to 85°F. This number was selected to be low enough that single-stage chillers with heat exchangers on the leaving condenser line could meet the requirement.

There are two exceptions to the requirement of § 6.5.6.2:

- Facilities that employ condenser water heat recovery for space heating with a minimum 30% recovery of the peak water-cooled condenser load at design conditions.
- Facilities that provide 60% or more of their service water heating from site solar or site recovered sources. Examples include heat recovery from cogeneration, condensate subcooling, and solar panels.

Heat-recovery systems for water heating can be broadly split into two categories: those that recover heat from condenser water and those that recover heat directly from the refrigerant. Both types of systems can provide service water temperatures up to 140°F. However, it may be more energy efficient to recover condenser heat at temperatures in the 100°F to 110°F range, supplemented by booster heaters to provide the desired DHW temperature, since the higher the condensing temperature, the lower the chiller efficiency. Health codes require that both systems use double-wall heat exchangers to separate potable water from either refrigerant or condenser water.

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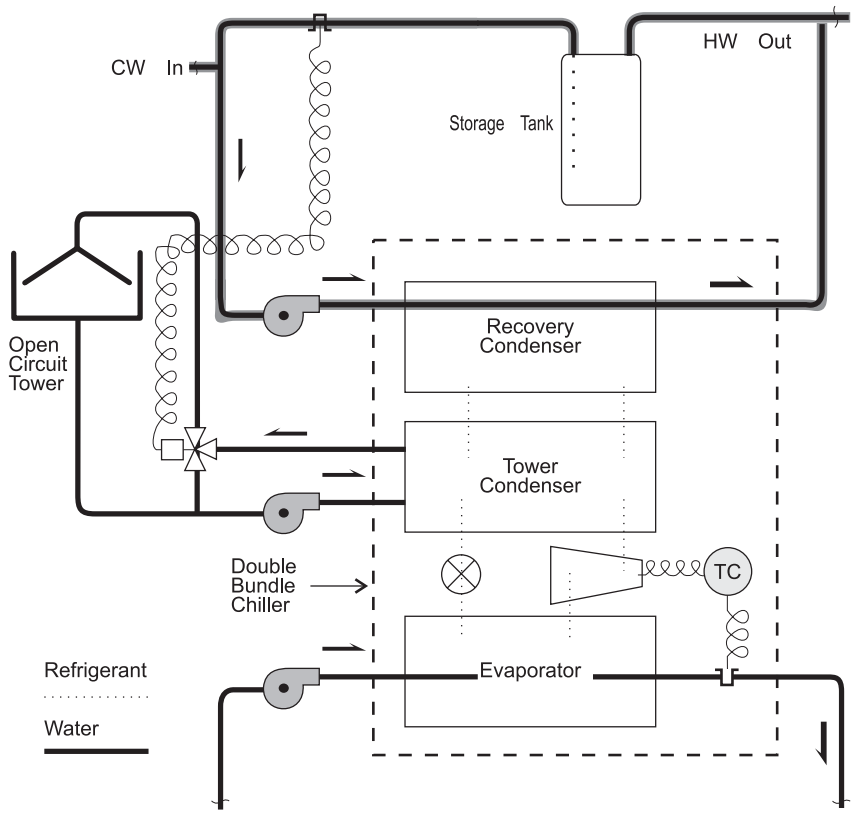

Figure 6-BB—Service Water Heating with Double Bundle Chiller

Heat may also be recovered from condenser water systems by utilizing a water-to-water heat pump that lifts the heat from the condenser water loop and uses it to charge a storage tank. These systems have COPs in the range of four to six, depending on the temperatures of both the condenser and service hot water loops. This design can be more efficient than direct condenser water heat recovery because it allows the chillers to operate at cooler condenser water temperatures. The heat pumps are placed in the loop upstream of the cooling tower and act as a first stage of heat rejection when in operation.

Heat recovery systems that extract energy directly from the refrigerant include double-bundle chillers and refrigerant desuperheaters. Both of these systems operate on the same principle: hot refrigerant gas on the way to the normal condenser is diverted through the auxiliary water-heating condenser as a first stage of cooling. Refrigerant desuperheater kits are available with a wide range of controls, capacities, and circuiting options. They can be used with refrigerated casework, commercial freezers and refrigerators, direct-expansion air-conditioning units, and heat pumps.

Sources of Site-Solar and Site-Recovered Energy (§ 6.5.6.1 and § 6.5.6.2)

Both of the energy recovery requirements provide exceptions where 60% of the air- or water-heating energy is provided from site-recovered or site-solar energy. Three possible sources are discussed below: cogeneration, solar, and subcooling of steam condensate.

Cogeneration

In general, cogeneration systems are generally only cost-effective in applications that have large and rather constant hot water or steam loads. Service hot-water systems for hotels, health-care facilities or sports facilities, with large pools, are all potential candidates. In preparing an evaluation of a cogeneration system, the following items should be carefully considered:

- Development of accurate hourly load profiles.
- Cost of power conditioning and isolation of sensitive circuits.
- Cost of maintenance.
- Availability of coincident electrical loads.
- Availability of utility excess power purchasing and their requirements for power conditioning.
- Economics of other high efficiency heat-generating alternatives.

Solar

Solar heating is best suited to projects where large quantities of low-temperature hot water are required, coupled with available space for collector arrays. Pools are an excellent application because the required temperatures are low (permitting the use of low-cost and durable unglazed collectors); the mass of water in the pool

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buffers the temperature swings; and freeze protection is accomplished by draining the collectors back into the pool. Other applications where solar should be considered include preheat of water for use in locker rooms, low-temperature process heating, and preheat of water for commercial laundries.

Subcooling of Steam Condensate
In steam systems, a heat exchanger upstream of the condensate receiver tank can be used for the dual purpose of heating service water and subcooling condensate to prevent flashing. Without subcooling, a portion of the heat in the condensate will be lost in the form of flash steam vented from the tank. By subcooling the steam, this energy is captured and put to good use. As the demands for steam and hot water are not likely to coincide, a storage system is generally recommended.

Exhaust Hoods (§ 6.5.7)

Kitchen Hoods (§ 6.5.7.1)
Individual kitchen exhaust hoods larger than 5000 cfm must be provided with makeup air sized for at least 50% of exhaust air volume that is: a) unheated or heated to no more than 60°F, and b) uncooled or cooled without the use of mechanical cooling. This is most commonly done with hoods with integral supplies that supply air either right at the face of the hood or into the hood.

The following exceptions apply to § 6.5.7.1:

- Where hoods are used to exhaust ventilation air that would otherwise exfiltrate or be exhausted by other fan systems. For instance, if the minimum ventilation outdoor air to a restaurant amounts to 50% of the hood exhaust rate, the requirements of this section may be fulfilled by transferring the air to the kitchen to provide makeup to the kitchen exhaust hood.
- Certified grease extractor hoods that require a face velocity no greater than 60 fpm. These hoods save energy by reducing the amount of air that must be exhausted, saving both fan energy and the energy required to condition makeup air.

Fume Hoods (§ 6.5.7.2)
Buildings with fume hood systems, such as laboratories, having a total exhaust rate greater than 15,000 cfm must include at least one of the following features:

- Variable air volume hood exhaust and room supply systems capable of reducing exhaust and makeup air volume to 50% or less of design values. VAV systems reduce fan energy as well as the energy required to condition makeup air. Modern fume hood control systems have become very reliable and provide airflow monitoring capability not usually found with constant volume systems.
- Direct makeup (auxiliary) air supply equal to at least 75% of the exhaust rate, heated no warmer than 2°F below room setpoint, cooled to no cooler than 3°F above room setpoint, no humidification added, and no simultaneous heating and cooling used for dehumidification control. Auxiliary supply systems can cause drafts at the hoods, reducing their capture effectiveness, and they cannot maintain close humidity control in the area around the hood. These systems have therefore fallen out of favor and have been replaced by variable air volume systems.
- Heat recovery systems to precondition makeup air from fume hood exhaust in accordance with § 6.5.6.1 (Exhaust Air Energy Recovery), without using any exception.

Radiant Heating Systems (§ 6.5.8)

Heating Unenclosed Spaces (§ 6.5.8.1)
This section requires that radiant heating must be used when heating is required for unenclosed spaces. An exception is made for loading docks equipped with air curtains.

Heating Enclosed Spaces (§ 6.5.8.2)
Radiant heating systems that are used as primary or supplemental enclosed space heating must conform to the governing provisions of the Standard, including, but not limited, to the following:

- Radiant hydronic ceiling or floor panels (used for heating or cooling).
- Combination or hybrid systems incorporating radiant heating (or cooling) panels.
- Radiant heating (or cooling) panels used in conjunction with other systems, such as variable air volume or thermal storage systems.

This section does not require that radiant systems be used for heating enclosed spaces.

Hot-Gas Bypass (§ 6.5.9)
All refrigeration systems have limited unloading capability. For direct expansion systems, if cooling loads are below the system's lowest step of unloading, suction temperatures will fall. Condensate on the cooling coil may freeze, clogging the coil, reducing airflow, and further reducing the load. Before long the entire coil may freeze, causing damage to the coil and, if liquid refrigerant subsequently slugs into the compressor, damage to the compressor as well. This situation occurs most frequently with VAV systems and/or systems with integrated economizers.

One solution is to install frost-stats, or low-limit thermostats, on coil suction

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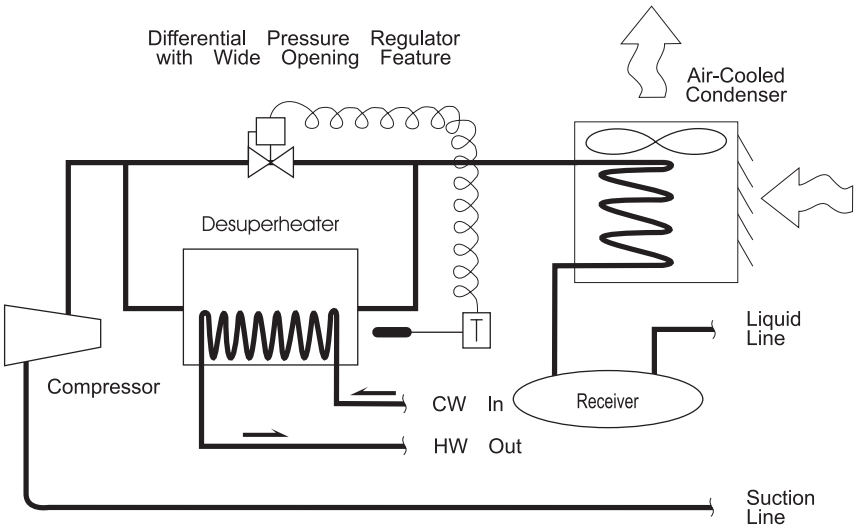

Figure 6-CC—Service Water Heating with Refrigerant Desuperheater

lines. However, this may result in excessive compressor cycling that may damage the compressor (depending on compressor type) and reduce the service life of both the compressor and starter contacts.

Low-load operation may also be a concern even for large rotary or centrifugal chillers whose unloading capabilities, while better than those for reciprocating or other small compressors, still do not allow stable operation at low loads (less than 20% to 25% or so). Equipment damage is usually prevented with proper controls and safety devices, but long periods of low-load operation can still cause excessive compressor cycling.

One way to resolve this problem is to provide hot-gas bypass or other means of false loading to maintain adequate evaporator pressures. With hot-gas bypass systems, hot-gas from the compressor discharge is injected into the compressor suction to false load the compressor so that it will operate stably at its lowest stage of unloading. This resolves the problem, but at the expense of increased energy usage at low loads.

To limit this energy waste, the Standard only allows the use of that hot-gas bypass or other false-loading evaporator pressure control systems if:

- The system is designed with multiple steps of unloading or continuous capacity modulation. The capacity of the hot-gas bypass is limited to 50% of the cooling capacity for systems 240,000 Btu/h or smaller and to 25% of the capacity for larger systems.
- The system is a unitary packaged system with a cooling capacity not greater than 90,000 Btu/h.

To avoid or minimize the use of hot-gas bypass, one or more of the following design options should be considered.

- Avoid over sizing equipment.
- Use multiple pieces of equipment in parallel, such as multiple chillers or compressors. If loads can be very low, the equipment may be unevenly sized, such as a 60-ton chiller with a 300-ton chiller.
- Specify as many steps of unloading as are available from the manufacturer. Particularly for large VAV rooftop units, additional steps of unloading are often available as factory standard options.
- Different centrifugal chiller designs can unload better than others. In particular, chillers with variable-speed drives can usually operate at lower loads than fixed speed chillers, particularly when condenser relief is possible. If many hours of low-load operation are expected, request minimum stable operating load points from competing manufacturers before making a final selection. To ensure performance, request written guarantee of capabilities.
- For water-cooled equipment, low-load performance can often be improved by reducing condensing temperatures.
- For chilled water systems, ensure that the system has sufficient water volume to prevent short cycling, which might make hot-gas bypass required. Most

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manufacturers include minimum system sizes in catalogs.

- Hot-gas bypass should not be expected to lower space-relative humidity. Space-relative humidity is reduced by increasing the space-sensible load in order to run the system longer. Humidity can be controlled by using discharge air control instead of space control, or by varying the volume of air at part load.

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Compliance Forms

Compliance forms are provided in the User's Manual to assist in understanding and documenting compliance with the HVAC requirements. Copies of the forms are provided both in printed and electronic form. Modifiable electronic forms are included on the CD distributed with the Manual, as well as available for download from the ASHRAE website. The HVAC system forms are organized in three parts and on five pages.

- Part I is used with the Simplified Approach Option (§ 6.3). This is the only form required with this compliance option.
- Part II, the Mandatory Provisions, consists of two pages and should be used with either the Prescriptive Path (§ 6.5) or Energy Cost Budget (§ 11) compliance methods. The first page contains header information, tables for entering equipment efficiencies for heating and cooling equipment, and checklists of general and special mandatory requirements. The second page contains the HVAC System Worksheet. Multiple copies of each page may be required to list all central heating and cooling equipment and all HVAC systems.
- Part III should only be used for the Prescriptive Path (§ 6.5) compliance method. Page one is a checklist of the prescriptive requirements and needs to be completed only once for each building. Page two addresses the fan power requirements.

Part I: Simplified Approach

This compliance approach may be used for small buildings with two or fewer floors and single, zone systems.

Header Information

Project Name. Enter the name of the project. This should agree with the name that is used on the plans and specifications or the common name used to refer to the project.

Project Address. Enter the street address of the project, for instance "142 Minna Street."

Date: Enter the date when the compliance documentation was completed.

City: The name of the city where the project is located.

Zip/Postal Code: Enter the zip or postal code of the project site.

HVAC Designer of Record/Telephone: Enter the name and the telephone number of the designer of record for the project. This will generally be the mechanical engineer or contractor.

Contact Person/Telephone: Enter the name and telephone number of the person who should be contacted if there are questions about the compliance documentation.

Checklist Qualification

Only small buildings less than 25,000 ft² and with two or fewer stories may use the Simplified Approach.

Requirements

This section of the form summarizes the Simplified Approach requirements. Each form is separated into two sections.

The upper part of the form contains a list of the requirements. Check each box to indicate that the requirement applies to the HVAC system and that the system complies with the requirement. If the requirement is not applicable, then leave the box unchecked.

The lower part of the form contains a table for entering heating and cooling capacities and efficiencies for comparison against the Standard. The rated capacity and efficiency for heating and cooling should be taken from manufacturers specifications.

The Minimum Efficiency columns should include values taken from Tables 6.8.1 and 6.3.2. The last column "Econ. Min. Efficiency" need only be completed if an exception to the economizer requirement is being taken, based on greater equipment efficiency (See Table 6.3.2).

Part II: Mandatory Provisions

This section of the compliance documentation summarizes the Mandatory Provisions. These apply with either the Prescriptive Path or Energy Cost Budget Method of compliance. The two pages of mandatory requirements are organized into three sections:

- The efficiency tables on Page 1 document that heating and cooling equipment meets or exceeds the efficiency requirements.
- The check boxes in the lower part of Page 1 demonstrate compliance with the general and special provisions of the Mandatory Provisions.
- The Systems Worksheet on Page 2 summarizes the requirements specific to air-handling systems.

Equipment Efficiency Tables

Enter the requested data for each piece of mechanical heating or cooling equipment using one entry per row. Identical pieces of equipment can be entered as a group on a single line. For each row, enter data from the mechanical equipment schedules and Tables 6.8.1 (A through G). For each row, enter data from the mechanical equipment schedules and Tables 6.2.1 (H through J).

Non-standard chillers are water-cooled centrifugal chillers that cannot operate at the ARI Standard 550/590 test conditions of 44°F chilled water supply and 85°F condenser water supply. Use the lower worksheet for these chillers (if any exist in the building).

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General and Specific Mandatory Provisions
The lower part of the Page 1 form contains the general and special system requirements. Check the box to indicate that the requirement applies to the HVAC system and that the system complies with the requirement. If the requirement is not applicable, then leave the box unchecked.

Systems Worksheet
Page 2 contains the mandatory requirements for HVAC systems. Data for each system or group of identical systems should be entered in the columns. The first five rows are data that can be obtained from the mechanical equipment schedules (system tag, supply airflow, supply external static pressure, supply fan motor rated horsepower, and outdoor air airflow). The remaining 11 rows contain the mandatory requirements. For each requirement enter the appropriate code from the notes below the table. For example, for the Automatic Shutdown requirement (§ 6.4.3.2.1), if a complying time switch with manual override is provided on the system the user should enter the code "C1."

Part III: Prescriptive Requirements

This section of the compliance documentation summarizes the prescriptive requirements. The first page has a checklist of the prescriptive requirements.

Prescriptive Economizer Requirements
Check all of the boxes that apply for HVAC systems in this project. Note: if systems are exempt from the economizer requirement, mark the basis for the exception in the space provided. If a requirement is not applicable, then leave the box unchecked.

Prescriptive Air-System Requirements
The next section contains the air-system requirements. Check all of the boxes that apply to HVAC systems in this project. If a requirement is not applicable, then leave the box unchecked.

Prescriptive Water-System Requirements
The next section contains the water-system requirements. Check all of the boxes that apply to HVAC systems in this project. If a requirement is not applicable, then leave the box unchecked.

Prescriptive Special System Requirements
Check all of the boxes that apply to HVAC systems in this project. If a requirement is not applicable, then leave the box unchecked. If none of the requirements are applicable, the form may be omitted.

Fan Power Limitations
Fill out the worksheet on Page 2 for each fan system with greater than 5 nameplate-rated horsepower. Identical fan systems may be combined into a single worksheet.

There are two options for showing compliance with the fan power limitation. Option 1 is shown at the top of the page. Option 2 is shown at the bottom. For each fan system only the top or the bottom part of the table will be completed.

Option 1 – Nameplate Horsepower
With this option, each of the fans in the system are listed in the table on the left. The option buttons are used to indicate the type of fan. The Tag is a reference to a schedule on the mechanical drawings. For each, the nameplate horsepower is listed in the last column and summed at the bottom of the table.

This value shall be less than the allowed nameplate horsepower calculated in the table on the right. The allowed nameplate horsepower is calculated by multiplying Design Supply Airflow Rate (CFM_S) times the allowance from Table 6.5.3.1.1A. A value of 0.0011 is used for constant volume systems and 0.0015 for variable volume systems.

Option 2 – Brake Horsepower
With Option 2, the allowed brake horsepower for the fan system is calculated in the top two tables of this section. The base allowance is calculated by multiplying the Design Supply Airflow Rate (CFM_S) times the Option 2 allowance from Table 6.5.3.1.1A. A value of 0.00094 is used for constant volume systems and 0.0013 for variable volume systems.

Additional brake horsepower is allowed for devices listed in Table 6.5.3.1.1B and described earlier in this chapter. Each device is listed along with the CFM through the device and the pressure drop allowance from Table 6.5.3.1.1B. The additional brake horsepower is calculated using the equation below. The additional allowances are summed and added to the base brake horsepower allowance in the left side table.

$$\mathrm{bhp}_{\mathrm{Addition}} = \frac{\mathrm{CFM}_i \times \mathrm{PD}_i}{4131} \qquad (6\text{-L})$$

With Option 2, it is necessary to calculate the installed brake horsepower for the fan system. The Installed Brake Horsepower table at the bottom of the form provides a means for making this calculation.

Each fan in the system is listed along with the Tag, which keys the fan to the mechanical schedules. A brief description of each fan is provided and the type of fan is indicated by choosing one of the option boxes.

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The brake horsepower for each fan is calculated based on the CFM of each fan; the pressure drop across the fan; and the efficiency of the fan, the drive (if applicable). Brake horsepower is given by the following equation:

(6-M)

$$bhp_i = \frac{CFM_i \times PD_i}{6350} \times \eta_{Fan} \times \eta_{Drive} \times \eta_{Motor}$$

The total brake horsepower from this worksheet shall be less than the total allowed brake horsepower.

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HVAC Simplified Approach Option — Part I

Project Name:	
Project Address:	Date:
City:	Zip:
HVAC System Designer of Record:	Telephone:
Contact Person:	Telephone:

Qualification

- ❑ The building is 2 stories or less in height and has a gross floor area is less than 25,000 ft^2.

Requirements

- ❑ (a) All systems serve a single HVAC zone.
- ❑ (b) Cooling (if any) is provided by a unitary packaged or split-system air conditioner that is either air-cooled or evaporatively cooled and meets the efficiency requirements shown in Table 6.8.1. List equipment in the table below.
- ❑ (c) The system has an air economizer as required by Table 6.5.1, with controls as required in Tables 6.5.1.1.3A and 6.5.1.1.3B. The economizer has either barometric or powered relief sized to prevent overpressurization of the building. Outdoor air dampers for the economizer use are provided with blade and jamb seals.
  - ❑ Exception: The cooling efficiency meets or exceeds the efficiency requirement in Table 6.3.2. Document in table below.
- ❑ (d) Heating (if any) shall be provided by a unitary packaged or split-system heat pump, a fuel-fired furnace, an electric resistance heater or a baseboard system connected to a boiler. All heating equipment meets the efficiency requirements of the Standard. List equipment in table below.
- ❑ (e) The outdoor air quantity is less than or equal to 3,000 cfm and less than or 70% of the supply air quantity at minimum outdoor air design conditions.
  - ❑ Exception: An energy recovery ventilation system is provided in accordance with the requirements in § 6.5.6.
- ❑ (f) The system shall be controlled by a manual changeover or dual setpoint thermostat.
- ❑ (g) Heat pumps equipped with auxiliary internal electric resistance heaters (if any) have controls to prevent supplemental heater operation when the heating load can be met by the heat pump alone.
- ❑ (h) The system controls do not permit reheat or any other form of simultaneous heating and cooling for humidity control.
- ❑ (i) Systems are provided with a time switch that (1) can start and stop the system under different schedules for seven different day-types per week; (2) is capable of retaining programming and time setting during a loss of power for a period of at least 10 h; (3) includes an accessible manual override that allows temporary operation of the system for up to 2 h; (4) is capable of temperature setback down to 55°F during off hours; and (5) is capable of temperature setup to 90°F during off hours.
  - ❑ Exception: System serves hotel/motel guest rooms.
  - ❑ Exception: System operates continuously.
  - ❑ Exception: System has both a cooling or heating capacity less than 15,000 Btu/h and a supply fan motor power greater than 3/4 hp.
- ❑ (j) Piping is insulated in accordance with Table 6.8.3. Insulation exposed to weather is suitable for outdoor service. Cellular foam insulation is protected from water and solar radiation.
  - ❑ Exception: Piping is located within manufactured HVAC units.
- ❑ (k) Ductwork and plenums are insulated in accordance with Tables 6.8.2A and 6.8.2B and sealed in accordance with Tables 6.4.4.2A and 6.4.4.2B.
- ❑ (l) Construction documents require air systems to be balanced in accordance with industry-accepted procedures to within 10% of design airflow rates.
- ❑ (m) Where separate heating and cooling equipment serve the same temperature zone, thermostats are interlocked to prevent simultaneous heating and cooling.
- ❑ (n) Exhausts are equipped with gravity or motorized dampers that will automatically shut when systems are not in use.
  - ❑ Exception: Design capacity is less than 300 cfm.
  - ❑ Exception: System operates continuously.
- ❑ (o) Systems have optimum start controls.
  - ❑ Exception: Supply air capacity is less than 10,000 cfm.

Equipment Efficiency

System Tag(s)	Mfg. & Model No.	Equipment Type	Heating			Cooling			
			Rated Capacity	Rated Efficiency	Minimum Efficiency	Rated Capacity	Rated Efficiency	Minimum Efficiency	Econ. Min. Efficiency

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HVAC Mandatory Provisions

Project Name:			
Project Address:			Date:
HVAC System Designer of Record:			Telephone:
Contact Person:			Telephone:
City:	Climate Zone:		
Zip:	1% Summer DB Temp:	1% Summer WB Temp:	99.6% Winter Temp:

Mandatory Equipment Efficiency Worksheet (§ 6.4.1.1)

System Tag	Equipment Type (Tables 6.8.1A through G)	Size Category (Tables 6.8.1A through G)	Sub-Category or Rating Condition (Tables 6.8.1A through G)	Units of Efficiency (Tables 6.8.1A through G)	Minimum Efficiency (Tables 6.8.1A through G) Rated ≥ Required
					≥
					≥
					≥
					≥
					≥
					≥
					≥

Mandatory Non-Standard Centrifugal Chiller Worksheet (§ 6.4.1.1)

System Tag	Leaving CHW Temperature (°F)	Entering CW Temperature (°F)	Condenser Flow Rate (gpm/ton)	Size Category (Tables 6.8.1H through J)	Minimum Efficiency (Tables 6.8.1H through J) Rated ≥ Required
					≥
					≥
					≥
					≥

General Mandatory Requirements

- ❑ Load calculations are provided for selection of all equipment and systems (§ 6.4.2).
- ❑ Stair vents, elevator shaft vents, gravity hoods, gravity vents and gravity ventilations are provided with motorized dampers.
  - ❑ Exception: Gravity dampers are used since the building is less than 3 stories or in climate zones 1–3.
  - ❑ Exception: No vents are required as these systems ventilate unconditioned zones.
- ❑ Piping insulation meets or exceeds the requirements of the Standard (§ 6.4.4.1.3).
- ❑ Construction documents require record drawings (§ 6.7.2.1), manuals (§ 6.7.2.2), system balancing (§ 6.7.2.3) and system commissioning (§ 6.7.2.4).

Special Mandatory Requirements

- ❑ Freeze protection or snow/ice melting systems (if any) have controls to prevent operation in warm weather (§ 6.4.3.7).
- ❑ Independent perimeter heating systems (if any) comply with the control requirements of § 6.4.3.1.1 and § 6.4.3.2.
- ❑ Independent heating and cooling thermostatic controls (if any) are interlocked to prevent crossover of set points (§ 6.4.3.2).

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Project Name:	
Contact Person:	Telephone:

Systems Worksheet (§ 6.4)

System Tag						
Supply CFM						
Supply ESP (in. w.c.)						
Fan System HP						
OA CFM (i.e. Outdoor Air CFM)						
Automatic Shutdown (§ 6.4.3.2.1)						
Deadband (§ 6.4.3.1.2)						
Setback Controls (§ 6.4.3.2.2)						
Setup Controls (§ 6.4.3.2.2)						
Optimum Start (§ 6.4.3.1.3)						
Zone Isolation (§ 6.4.3.1.4)						
Shutoff Dampers (§ 6.4.3.3.3)						
Heat Pump Aux Heat (§ 6.4.3.4)						
Humidifier Preheat (§ 6.4.3.5)						
Humidification/Dehumidification Deadband (§ 6.4.3.6)						
Ventilation Control (§ 6.4.3.8)						
Duct/Plenum Insulation (§ 6.4.4.2.1)						
Duct Sealing Levels (§ 6.4.4.2.1) Supply/Return						
Duct Leakage Test (§ 6.4.4.2.2)						

In the table above, enter the appropriate codes from this list:

Shutdown
- *C1 Complying nonresidential time switch with override*
- *C2 Complying residential time switch with override*
- *N1 N/A continuous operation*
- *N2 N/A ≤15 kbtu/h or ≤3/4 hp*
- *N3 N/A hotel/motel guestroom*

Dead Band
- *C1 Dual setpoint control*
- *C2 Manual change over control*
- *N1 N/A special occupancy (requires approval)*
- *N2 N/A heating or cooling only*

Setback Controls
- *C1 Setback provided (down to 55F)*
- *N1 N/A continuous operation*
- *N2 N/A ≤15 kbtu/h or ≤3/4 hp*
- *N3 N/A 99.6% Win DB>40F*
- *N4 N/A radiant heating*
- *N5 N/A no heating*

Setup Controls
- *C1 Setup provided (up to 90F)*
- *N1 N/A continuous operation*
- *N2 N/A ≤15 kbtu/h or ≤3/4 hp*
- *N3 N/A 1% Sum DB<=100F*
- *N4 N/A no cooling*

Optimum Start
- *C1 Optimum start provided*
- *N1 N/A continuous operation*
- *N2 N/A ≤15 kbtu/h or ≤3/4 hp*
- *N3 N/A supply<=10,000 cfm*

Shutoff Dampers
- *C1 Motorized shutoff dampers on OA and Exh*
- *C2 Gravity shutoff dampers on OA and Exh*
- *N1 N/A continuous operation*
- *N2 N/A ≤15 kbtu/h or ≤3/4 hp*
- *N3 N/A OA/EA <=300 cfm*

Zone Isolation
- *C1 Isolation zones provided*
- *N1 N/A continuous operation*
- *N2 N/A ≤15 kbtu/h or ≤3/4 hp*
- *N3 N/A all zones on same schedule*
- *N4 N/A OA/EA <=5,000 cfm*

Heat Pump Aux Heat
- *C1 Complying controls provided*
- *N1 N/A system is not a heat pump*
- *N2 N/A auxiliary is not electric or is not provided*
- *N3 N/A heat pump covered by NAECA*

Humidifier Preheat
- *C1 Complying controls provided*
- *N1 N/A no humidifier*

Humidification/Dehumidification Dead Band
- *C1 Complying controls provided*
- *N1 N/A no humidification and/or dehumidification*

Duct/Plenum Insulation
- *C1 Complying insulation provided*
- *N1 N/A all ducts located in conditioned space*

Duct Sealing
- *Enter highest seal level (A, B or C) for supply and return*

Duct Leakage Test
- *Y Ducts will be tested for leakage*
- *N Ducts will not be tested for leakage*

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HVAC Prescriptive Requirements

Project Name:	
Contact Person:	Telephone:

Prescriptive Checklist

Prescriptive Economizers (§ 6.5.1)

- ❑ Systems employ airside economizers (§ 6.5.1.1).
- ❑ Economizer provides up to 100% design airflow in outdoor air (§ 6.5.1.1.1).
- ❑ Economizer is integrated with the mechanical cooling system (§ 6.5.1.1.2 and § 6.5.1.3).
- ❑ Economizer high limit shutoff complies with § 6.5.1.1.3.
- ❑ Economizer dampers meet or exceed leakage requirements (§ 6.5.1.1.4).
- ❑ System provides relief for up to 100% design airflow in outdoor air (§ 6.5.1.1.5).
- ❑ Economizer complies with the heating system impact requirements (§ 6.5.1.4).
- ❑ Systems employ waterside economizers.
- ❑ Economizer can provide 100% of the load at either the outdoor conditions of 50°F db/45°F wb or 45°F db/40°F wb where required for dehumidification purposes (§ 6.5.1.2.1).
- ❑ Precooling coils and heat exchangers have either a ≤ 15 ft of WC pressure drop or are bypassed when economizer is not in use (§ 6.5.1.2.2).
- ❑ Economizer is integrated with the mechanical cooling system (§ 6.5.1.3).
- ❑ Economizer complies with the heating system impact requirements (§ 6.5.1.4).
- ❑ Systems are exempt from the economizer requirements.

Specify economizer exemptions:_____

_____

_____

_____

Prescriptive Air-System Requirements

- ❑ Simultaneous Heating and Cooling (§ 6.5.2.3).
- ❑ Zone minimums were set to meet the requirements of *Standard 62*.
- ❑ Zone minimums were set to ≤0.4 cfm/ft^2 of zone conditioned floor area.
- ❑ Zone minimums are less than 300 cfm.
- ❑ Other (requires special documentation and approval).
- ❑ Humidity controls (if any) comply with the requirements of § 6.5.2.3.
- ❑ Systems that employ hydronic cooling and have humidification (if any) use a waterside economizer that complies with § 6.5.1.
- ❑ Variable air volume fan controls comply with the requirements of § 6.5.3.2.

Prescriptive Water-System Requirements

- ❑ Three-pipe systems are not used (§ 6.5.2.2.1).
- ❑ Two-pipe changeover heating/cooling systems (if any) comply with the requirements of § 6.5.2.2.2.
- ❑ Hydronic (ground- or water-loop) heat pump systems that have equipment for both loop heat addition and loop heat rejection (if any) comply with the requirements of § 6.5.2.2.3.
- ❑ System pumps greater than 10 hp employ variable flow controls (§ 6.5.4.1), pump isolation (§ 6.5.4.2) and temperature reset (§ 6.5.4.3).

Prescriptive Special System Requirements

- ❑ All heat rejection equipment with motors ≥ 7.5 hp employ controls that comply with § 6.5.5.
- ❑ Exhaust Air Energy Recovery: all fan systems that have both a design supply capacity of ≥ 5,000 cfm and a minimum outdoor air supply of ≥ 70% of the design supply air employ an energy recovery system that complies with § 6.5.6.1.
- ❑ Heat recovery for service water heating is provided for facilities that operate continuously, have a total water-cooled heat rejection capacity exceeding 6,000,000 btu/h, and have a design service water heating load exceeding 1,000,000 btu/h. The heat recovery system (if any) complies with § 6.5.6.2.
- ❑ Kitchen hoods with exhaust flows > 5000 cfm comply with the requirements of § 6.5.7.1.
- ❑ Fume hoods with a total exhaust system flow > 15,000 cfm comply with the requirements of § 6.5.7.2.
- ❑ Radiant heaters complying with § 6.5.8.1 are used to heat unenclosed spaces (if any).
- ❑ The cooling equipment with hot-gas bypass controls (if any) meets the unloading requirements of § 6.5.9.

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Project Name:	
Contact Person:	Telephone:

Option 1 – Nameplate Horsepower

Installed Nameplate Horsepower

Tag	Description	Supply	Return	Exhaust	Series FPB	Other	Nameplate Horsepower
		❍	❍	❍	❍	❍	
		❍	❍	❍	❍	❍	
		❍	❍	❍	❍	❍	
		❍	❍	❍	❍	❍	
		❍	❍	❍	❍	❍	

Allowed Nameplate Horsepower

Design Supply Airflow Rate (CFM_S)	
Fan Nameplate Horsepower Allowance from Table 6.5.3.1.1A	
Total Allowed Nameplate Horsepower	

Option 2 – Brake Horsepower

Allowed Fan Brake Horsepower

Design Supply Airflow Rate (CFM_S)	
Fan Brake Horsepower Allowance from Table 6.5.3.1.1A	
Base Allowance (Line1 x Line 2)	
Additional Brake Horsepower Allowance	
Total Allowed Brake Horsepower	

Pressure Drop Adjustments for Qualifying Devices

Tag	Device Description	Pressure Drop from Table 6.5.3.1.1B	CFM through Device	Additional Brake Horsepower Allowance

Installed Brake Horsepower

Tag	Description	Supply	Return	Exhaust	Series FPB	Other	CFM	Pressure Drop (PD)	η_{Fan}	η_{Drive}	η_{Motor}	Brake Horsepower
		❍	❍	❍	❍	❍						
		❍	❍	❍	❍	❍						
		❍	❍	❍	❍	❍						
		❍	❍	❍	❍	❍						
		❍	❍	❍	❍	❍						

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7. Service Water Heating

equipment can be increased.

General Information (§ 7.1)

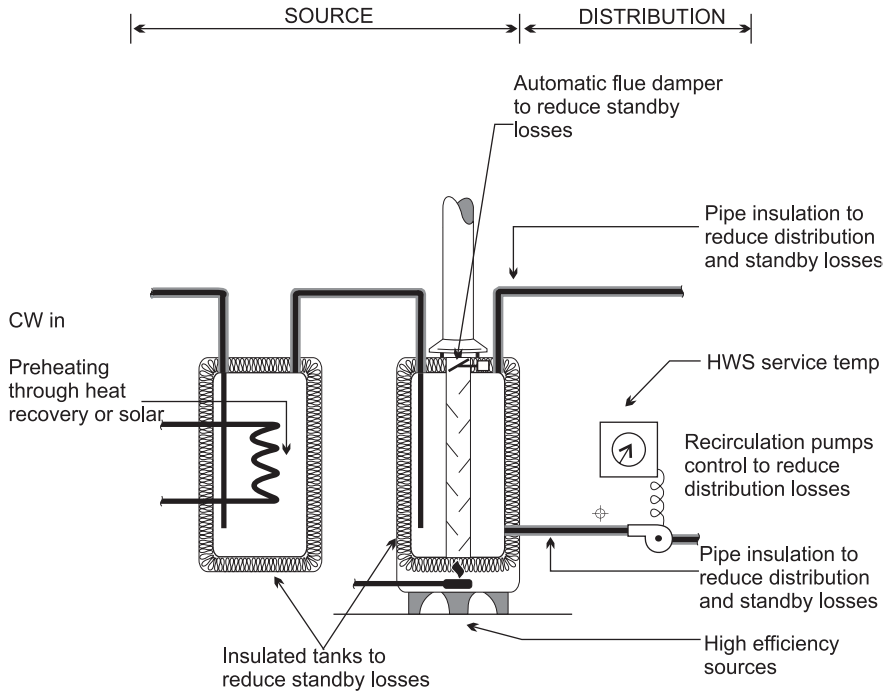
SOURCE
DISTRIBUTION
Automatic flue damper to reduce standby losses
Pipe insulation to reduce distribution and standby losses
CW in
Preheating through heat recovery or solar
HWS service temp
Recirculation pumps control to reduce distribution losses
Pipe insulation to reduce distribution and standby losses
High efficiency sources
Insulated tanks to reduce standby losses

Figure 7-A—Elements Covered by § 7 of the Standard

General Design Considerations

For some building types, service water heating can be a major energy consumer. In hotels, for example, water heating accounts for 25% to 40% of the total energy usage. Fortunately, this component of energy usage is easily controlled by applying some basic, cost-effective design practices, as shown in Figure 7-A and described below:

- *Hot water use* is reduced by using flow limiting or metering terminal devices;
- *Standby losses* are limited by using heat traps and thermal insulation;
- *Distribution losses* can be reduced through thermal insulation and circulation-pump controls or eliminated through point-of-use heaters;
- *Waste heat* or *solar energy* can be harnessed to meet part of the load; and
- *Efficiency* of the water heating

Inch-Pound and Metric (SI) Units

The Standard is available in two versions. One uses inch-pound (I-P) units, which are commonly used in the United States. The other version uses metric (SI) units, which are used in Canada and most of the rest of the world. Most of the examples and tables in this chapter use inch-pound units; however, where it is convenient, dual units are given in the text. The SI units follow the I-P units in parenthesis. In addition, the following table may be used to convert I-P units to SI units.

	I-P Units		**SI Units**
Length	ft	× 0.3048	= m
	in	× 25.4	= mm
Area	ft²	× 0.0929	= m²
Power	Btu/h	× 0.2928	= W
	Btu/h	× 0.0002928	= kW
Liquid Flow	gpm	× 0.0757682	= l/s
Volume	gal	× 3.785412	= l
R-factor	h·ft²·°F/Btu	× 0.1762	= m²·°C/W

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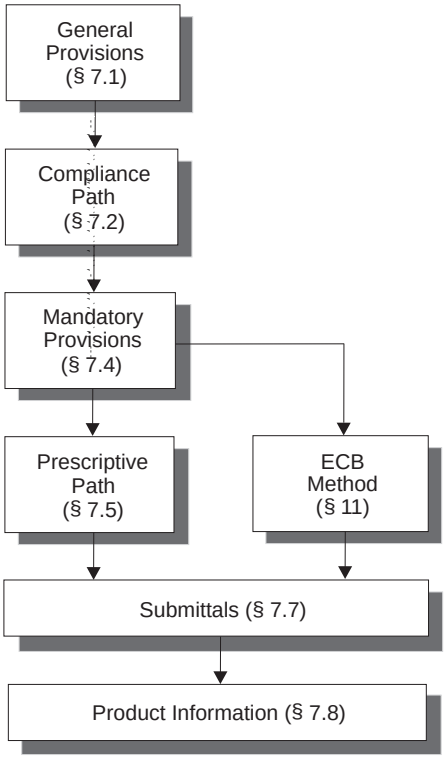

Figure 7-B—Compliance Options

The requirements described in this chapter apply to service water-heating equipment and systems (including combination space-conditioning and water-heating systems). However, the principles presented here could apply to energy-efficient process water-heating systems and equipment as well. Requirements for space-conditioning boilers and distribution systems are covered in Chapter 6.

Although compliance with the Standard assures a minimum level of water heating system performance, the designer may wish to investigate designs that exceed these requirements. The use of heat recovery, solar energy, or high-efficiency equipment may contribute to an efficient system that exhibits an excellent return on investment. Energy-efficient measures might include: automatic shutoff devices for lavatories; low-water usage or low-temperature appliances, including residential and commercial clothes washers and dishwashers; and recovering heat from gray water. In addition, designers are encouraged to compare the first and operating costs of large centralized systems with smaller distributed systems. Centralized systems are likely to be cost-effective in high usage facilities such as hotels and motels, multifamily residences, dormitories, laboratories, food courts, and prisons to name a few. Distributed systems are best applied in low usage facilities or where the usage is widely distributed such as office and retail facilities.

Scope (§ 7.1.1)

This chapter covers the Standard's requirements for service water-heating equipment and systems. Service water heating refers to heating water for domestic or commercial purposes other than space heating or process requirements. This includes, but is not limited to, the production and distribution of hot water for:

- Restrooms;
- Showers;
- Laundries;
- Kitchens;
- Pools and spas;
- Living units in high-rise residential buildings and hotels.

When water heaters are replaced in existing buildings, the replacement equipment must meet the requirements of the Standard (§ 7.1.1.2 and § 7.1.1.3).

Residential water heaters are also covered by the National Appliance Energy Conservation Act (NAECA). The efficiency requirements of NAECA are consistent with those of the Standard.

The Energy Policy Act (EPAct) of 1992, established, among many other provisions, federal minimum performance requirements for commercial boilers, commercial water heaters, and hot-water storage tanks. Commercial water heaters covered by EPAct are exempt from any labeling requirements of *Standard 90.1*.

However, minor alterations to a water heating system, such as extending the pipes to new fixtures or installing valves, would not trigger an upgrade to the service water heating system.

Compliance (§ 7.2)

The majority of § 7's requirements are Mandatory Provisions that must always be satisfied. There are also a few Prescriptive Requirements; the designer may choose to meet these or use the Energy Cost Budget (ECB) method described in Chapter 11.

For designers not familiar with the definitions, concepts, and calculation methods used in the following pages, a reference section is provided at the end of this chapter.

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Mandatory Provisions (§ 7.4)

All Mandatory Provisions must be complied with, regardless of whether the designer chooses to follow the prescriptive path or the ECB Method of compliance.

System Sizing (§ 7.4.1)

The Standard requires that load calculations be performed to determine the necessary size of water-heating systems, but the Standard does not directly limit oversizing. This same approach is taken in § 6.4.2 with regard to HVAC system sizing. The Standard assumes that if designers and contractors are required to select equipment based on calculated loads, oversizing will be limited as a result. Oversizing of equipment generally wastes energy through increased standby losses (due to the larger surface area of bigger tanks) and reduced heater efficiency (due to cycling).

The Standard requires that design loads be calculated using either manufacturers' published guidelines or generally accepted engineering standards and handbooks acceptable to the adopting authority. One resource is the design procedures in Chapter 49 of the 2003 ASHRAE *Handbook—HVAC Applications*. The designer may also use procedures developed by professional organizations or equipment manufacturers.[1] The 2003 ASHRAE *Handbook—HVAC Applications* presents a number of calculation methods for determining the design loads. The appropriate method depends both on the application (residential, food service, commercial laundry, etc.) and the type of system (storage heater or instantaneous). The various design load calculation methods are briefly summarized below:

- *Method 1, Heater with Storage for Standard Application*. This method is performed graphically using standardized charts representing heater recovery capacity (in gallons per hour per unit) as a function of tank storage size. Often there are multiple lines on the graphs representing variations in occupancy (such as number of apartments in a building or gender of dormitory occupants). This method is presented in Example 7-A.
- *Method 2, Heater with Storage for Standard Applications with Mixed Loads*. This method is similar to method 1, with the additional step of combining the results of multiple graphs. The recovery rates for each step are added, as are the storage capacities. Chapter 49 of the 2003 ASHRAE *Handbook—HVAC Applications* gives an example for a dormitory with food service.
- *Method 3, Heater with Storage from a Fixture Count*. This method is performed in three steps: (1) the total hourly draw of all fixtures in the facility is added together to produce the "possible maximum demand;" (2) the resulting number is multiplied by a "demand factor" to produce the "probable maximum demand" which equates to the heater recovery rate; and (3) the storage tank capacity is obtained by multiplying the "possible maximum demand," (step 1) with a "storage capacity factor." Table 6, Chapter 49, of the 2003 ASHRAE *Handbook—HVAC Applications* provides fixture demands, demand factors, and storage capacity factors for a wide variety of occupancies.
- *Method 4, Instantaneous and Semi-Instantaneous Water Heaters*. This method is performed in two steps: (1) the total number of "fixture units" is compiled from a count of fixtures and tables of "fixture units" for different applications; and (2) the heater capacity in gallons per minute or gallons per hour is obtained from graphs of heater output capacity versus fixture units. The referenced tables and graphs can be found in manufacturer's engineering guides and in Chapter 49 of the 2003 ASHRAE *Handbook—HVAC Applications*.

Reference material and example calculations for all of these methods are in Chapter 49 of the 2003 ASHRAE *Handbook—HVAC Applications*.

In sizing water-heating systems, there is a relationship between the storage capacity of the tank and the output capacity of the heater. A smaller heater can be used if the tank is larger; conversely, a smaller tank can be used with larger heater. Most of the calculation procedures consider both storage capacity and heater size but may not provide assistance in finding the optimum combination.

The right combination will depend on a number of factors including available space, equipment cost, and concern about standby loss. A smaller tank and larger heater will generally have a smaller footprint, a higher first cost, and a lower standby loss. A larger tank and smaller heater will generally have a larger footprint, a lower first cost, and a higher standby loss. In all cases premanufactured heaters and tanks will come in discrete sizes; the first cost will be lowest when you can utilize the total capacity of both the heater and tank.

In addition to sizing of heaters and storage tanks, Chapter 49 of the 2003 ASHRAE *Handbook—HVAC Applications* also provides useful information on other aspects of service water-heating systems.

These include:

- Special considerations in piping for commercial kitchens;
- Problems of water quality and protection from corrosion and scale;

[1]. When using a manufacturer's sizing method, designers are encouraged to compare the results to those obtained from the applicable method from the 2003 *ASHRAE Handbook—HVAC Applications*. Manufacturer's sizing methods in general will result in larger equipment capacities and costs.

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- Application and design of dual-temperature systems;
- Health and sanitation concerns; and
- Numerous references providing water use temperatures for a range of building and system types.

For information about the sizing of distribution piping, consult Chapter 35 of the 2001 ASHRAE *Handbook—Fundamentals*.

Equipment Efficiency (§ 7.4.2)

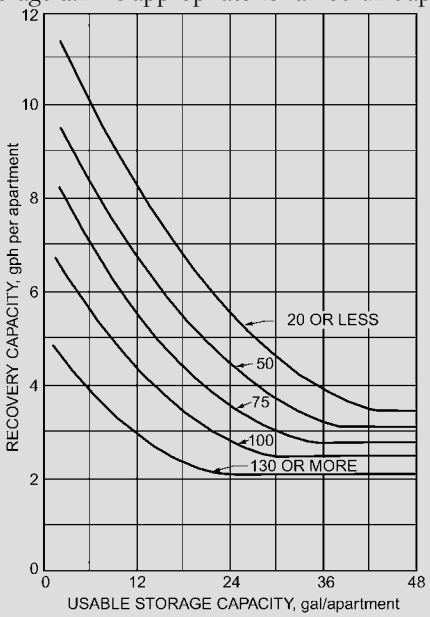
The Standard has efficiency requirements for water heaters and hot-water supply boilers that are not covered by the National Appliance Energy Conservation Act (NAECA) of 1987. NAECA is a Federal standard that specifies the minimum performance of residential and small commercial space-heating, space-cooling, and water-heating equipment. NAECA's efficiency requirements for water heaters include:

- All types of electric heaters at or below 12 kW input (including heat-pump water heaters and instantaneous heaters);
- Fuel-fired storage heaters at or below 75,000 Btu/h input for gas, 105,000 Btu/h input for oil;
- Fuel-fired instantaneous heaters at or below 200,000 Btu/h input for gas, 210,000 Btu/h input for oil;
- All fuel-fired pool and spa heaters.

Example 7-A—Sizing Service Water Heater Equipment

Q

What size heater and storage tank is appropriate for an 80-unit apartment building?



A

The graph above is a reproduction of Figure 19 from Chapter 49 of the 2003 ASHRAE *Handbook—HVAC Applications, I-P Edition*.

Any heater and storage tank combination that falls on the curve for 75 units would satisfy the load. Selection A is the smallest heater with its corresponding storage size. Selection B represents a larger heater that allows for a smaller storage tank. Either system would satisfy the load; the final decision should be based on economics and available space.

	Selection A		**Selection B**	
	Per Unit	**Total**	**Per Unit**	**Total**
Recovery Capacity (GPH)	2.75× 80	= 220	5× 80	= 400
(Does not account for system heat loss. Add system heat loss to loads calculated here.)				
Usable Storage	32× 80	= 2,560	14× 80	= 1,120
(Gallons)		×1.4		×1.4
Actual Storage (Gallons)		**3,600**		**1,600**
(Assuming 70% useful storage capacity)				

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Table 7.8 of the Standard presents the minimum required efficiencies for all water-heating equipment including NAECA-covered equipment, water heaters, and hot-water supply boilers. Equipment is required to have both a minimum heater efficiency (thermal efficiency) and a maximum standby loss. Smaller equipment, which falls under NAECA, is required to meet a minimum energy factor, which is a combined measure of thermal efficiency and standby loss. Table 7.8 classifies equipment by type (storage, instantaneous, etc.), fuel, capacity (input rating), input-to-volume ratio, and/or storage size. Examples 7-B through 7-D demonstrate how these equipment categories are applied.

For all the categories of equipment in Table 7.8 not covered by NAECA or EPAct, it is the manufacturer's responsibility to label the equipment as complying with the Standard (see § 6.4.1.5.1). The manufacturer will also provide the required data for calculation of the requirements. Unfired storage tanks are required to be insulated to *R*-12.5 (*R*-2.2), in accordance with Table 7.8. The standby loss requirement is waived on hot-water supply boilers and storage water heaters that meet all four of the following:

- Over 140 gallons (530 liters) measured storage capacity;
- Tank surface with a thermal insulation of R-12.5 (R-2.2) or more;
- No standing pilot light; and
- Fuel-fired heaters that have a flue damper or fan-assisted combustion.

This exception is provided to overcome the practical difficulties of testing large units with conventional test procedures.

Designers may wish to evaluate options for equipment with higher efficiencies than those required by the Standard. Non-condensing gas- and oil-storage water

Example 7-B—Equipment Efficiency Requirements, Hot-Water Supply Boiler

Q

A hot-water supply boiler consists of a gas-fired heater, circulation pump, and storage tank. The heater is rated at 1,825,000 Btu/h input and 1,497,000 Btu/h output. The heater storage capacity is 45 gallons, and its standby losses are 4,000 Btu/h. The storage tank has a 400-gallon capacity and is insulated to *R*-16 with sprayed-on polyurethane foam. Does it comply with the Standard?

A

The storage tank is unfired and insulated to *R*-16. This complies with the requirement for "Unfired Storage Tanks" in Table 7.8 (insulation *R*-value greater than *R*-12.5). The heater thermal efficiency and input-to-volume ratio are given by:

$$E_t = \frac{Q_{out}}{Q_{in}} = \frac{1{,}497{,}000}{1{,}825{,}000} = 82\%$$

$$\text{Input-to-Volume Ratio} = \frac{Q_{in}}{V_{heater}} = \frac{1{,}825{,}000\,Btu/h}{45\,gal} = 40{,}556\ Btu/h \cdot gal$$

The heater falls under the equipment type, "Hot Water Supply Boilers Gas," in the subcategory of greater than 4,000 Btu/(h·gal) and greater than 10 gallons of storage. Table 7.8 sets the following requirements for the heater: the minimum allowable thermal efficiency is 80% and the maximum allowable standby loss is given by:

$$SL = \frac{Q}{800} + 110\sqrt{V} = \frac{1{,}825{,}000}{800} + 110\sqrt{45} = 3019\,\text{Btu/h}$$

The heater thermal efficiency complies; its 82% efficiency is greater than the 80% required. However, the heater standby loss does not comply; its 4,000 Btu/h loss is greater than the maximum 3,019 Btu/h permitted. In order to comply, the heater needs additional thermal insulation to reduce its standby loss below 3,019 Btu/h. As it is impractical to blanket this unit in the field, the designer should request a model with more insulation from the manufacturer or select another unit that complies.

Example 7-C—Equipment Efficiency Requirements, Heat Pump Pool Heaters

Q

A heat pump system is used to heat the pool water, the heating capacity is 50,000 Btu/h, and the COP is 3.8 tested according to ASHRAE 146. Does it comply with the Standard?

A

No. The minimum required efficiency is COP 4.0 for all sizes of heat pump pool heaters.

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heaters are available with thermal efficiencies as high as 88%; condensing models are available with recovery efficiencies up to 95%. Standby losses are reported as low as 0.40%/h for storage gas models. Storage electric resistance heaters are available with thermal efficiencies up to 99.9% and standby losses down to 0.06%/h. Air-source heat-pump water heaters have COPs up to 3.8.

Example 7-D—Equipment Efficiency Requirements, Electric-Resistance Water Heater

Q

An 82-gallon electric-resistance storage heater has two 7.5 kW heating elements wired for non-simultaneous operation. The energy factor (*EF*) is 0.87. Does it comply with the Standard?

A

Since the elements are wired for non-simultaneous operation, the input rating of this model is 7.5 kW and its efficiency requirements are found in the Size Category ≤ 12kW (a category covered by NAECA). Table 7.8 requires that the energy factor of this unit be greater than or equal to:

$$EF_{min} = 0.97 - (0.00132 \times V) = 0.97 - 0.00132 \times 82 \text{ gal} = 0.86$$

This heater complies because its energy factor is greater than the minimum requirement.

Example 7-E—Equipment Efficiency Requirements, Condensing Gas Water Heater

Q

An instantaneous condensing gas water heater has the following characteristics: 1,000,000 Btu/h input; 23 gallon storage; 93% thermal efficiency; and 1,500 Btu/h standby loss. Does it comply with the Standard?

A

The water heater's input-to-volume ratio is given by:

$$\text{Input-to-Volume Ratio} = \frac{Q_{in}}{V_{heater}} = \frac{1{,}000{,}000\left(Btu/h\right)}{23\left(gal\right)} = 43{,}478 Btu/h \cdot gal$$

As shown in the subcategory column of Table 7.8, an input-to-volume ratio greater than or equal to 4,000 Btu/h·gal puts this heater in the "Gas Instantaneous Water Heater" category (lower input-to-volume ratios would make this a "Gas Storage Water Heater" for rating purposes). For a tank volume greater than 10 gallons, Table 7.8 sets the following requirements for the water heater: the required minimum efficiency is 80% and the required maximum standby loss is given by:

$$\text{SL} = \frac{\text{Q}}{800} + 110\sqrt{\text{V}} = \frac{1{,}000{,}000}{800} + 110\sqrt{23} = 1{,}778\,\frac{\text{Btu}}{\text{h}}$$

The heater complies because its thermal efficiency is greater than the minimum requirement and the standby loss is less than the maximum limit.

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Temperature Controls (§ 7.4.4.1 and § 7.4.4.3)

Water-heating systems are required to have controls that are adjustable down to a 120°F (49°C) setpoint or lower. An exception is made where a higher setting is recommended by the manufacturer to prevent condensation and possible corrosion. To comply with this requirement, the water heater must have thermostatic control with an accessible setpoint. This setpoint must be adjustable down to whichever is lower: 120°F (49°C) or the minimum manufacturer's recommended setting to prevent condensation. Both standby and distribution losses will be minimized by designing a system to provide hot water at the minimum temperature required. Table 7-A summarizes the recommended hot water design temperatures from Table 2, Chapter 49, of the 2003 ASHRAE *Handbook—HVAC Applications*.

In addition to the potential energy savings, maintaining water temperature as low as possible reduces corrosion and scaling of water heaters and components. Another important benefit is improved safety with respect to scalding. Accidental scalding from temperatures as low as 140°F is responsible for numerous deaths each year. The Standard requires automatic temperature controls for public lavatory faucets to limit the outlet temperature to 110°F (43°C).

Designers should be aware that the bacteria that causes Legionnaire's disease has been found in service water heating systems and can colonize in hot water systems maintained below 115°F. Careful maintenance practices can reduce the risk of contamination. In health-care facilities or service-water systems maintained below 140°F, periodic flushing of the fixtures with high temperature water or other biological controls may be appropriate. Refer to the ASHRAE position paper on Legionellosis for further information.

Table 7-A—Service Water Temperatures

Use	Temperature, °F
Lavatory	
Hand washing	105
Shaving	115
Showers and tubs	110
Therapeutic baths	95
Commercial and institutional laundry	<180
Residential dishwashing and laundry	140
Surgical scrubbing	110
Commercial spray-type dishwashing as required by N.S.F.	
Rack-type	>150 wash 180 to 195 final rinse
Single tank conveyor-type	>160 wash 180 to 195 final rinse
Multiple tank conveyor-type	>150 wash >160 pumped rinse 180 to 195 final rinse
Chemical sanitizing-type (see manufacturer. for actual temperature required)	140 wash >75 rinse

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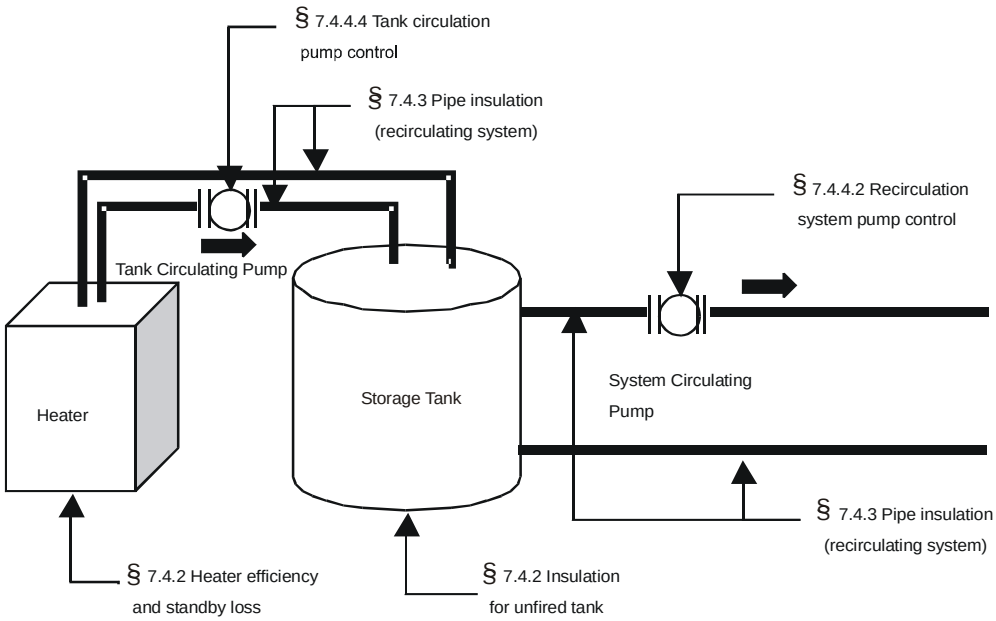
§ 7.4.4.4 Tank circulation pump control
§ 7.4.3 Pipe insulation (recirculating system)
§ 7.4.4.2 Recirculation system pump control
Tank Circulating Pump
Heater
Storage Tank
System Circulating Pump
§ 7.4.3 Pipe insulation (recirculating system)
§ 7.4.2 Heater efficiency and standby loss
§ 7.4.2 Insulation for unfired tank

Figure 7-C—Requirements for Circulating Systems and Remote Heaters with Storage Tanks

Distribution Losses (§ 7.4.3 and § 7.4.4.2)

Distribution losses affect two aspects of building energy: the energy required to make up for the lost heat and the additional load that can be placed on the space cooling system if the heat is released to the conditioned space. These losses can be limited through two primary strategies: containing the hot water in a storage tank when not required (through heat traps and controls on circulating pumps) and insulating the storage tank and pipes. The Standard's requirements differ for circulating and noncirculating systems. Systems without heat traps, regardless of whether they have circulation pumps, are treated as circulating systems.[2] Special requirements are made for the control of circulating pumps between heaters and hot-water storage tanks. The Standard's requirements for circulating systems are shown in Figure 7-C.

Circulating Systems

In circulating systems, the hot water is exposed to loss throughout the entire distribution system as long as the water is circulating. For these systems, the entire distribution piping system must be insulated. The Standard requires controls for circulation pumps to limit the circulation to those times when hot water is required. These controls are applicable to the pumps used to circulate water throughout a distribution system and the pumps used to circulate water between a heater and separate hot-water storage tank. As described below, there are a number of circulation control methods available. They differ in their sophistication of predicting or sensing demand.

Insulation (§ 7.4.3)

In circulating systems, the entire hot-water supply and return distribution system must be insulated to the requirements of Table 6.8.3 of the Standard. These pipe insulation requirements are summarized in Table 7-B. No insulation is required for piping that operates below 105°F. As demonstrated in this table, only ½ in. to 1 in. of closed-cell foam or fiberglass is typically required for service hot-water systems operating at 105°F and above.

In both circulating and noncirculating systems, the supply and return piping between a heater and hot-water storage tank must be insulated. Hot-water heaters and hot-water storage tanks must be insulated to meet the standby loss requirements previously described

Equivalent thicknesses for insulations of other conductivities are given by the following formula.

$$T = R_{out} \times \left[\left(1 + \frac{t}{R_{out}} \right)^{\frac{K}{0.28}} - 1 \right] \quad (7\text{-A})$$

2. The heat trap requirement (§ 7.4.6) applies only to heaters and storage tanks serving a "noncirculating" system. In lieu of heat traps, one could, in theory, apply pipe insulation in accordance with the requirements for circulating systems. In practice, the heat traps will be far less expensive.

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T = minimum required insulation thickness for proposed material (in.),
R_{out} = actual pipe outside radius (in.),
t = minimum insulation thickness (in.), specified in Table 7-B for a conductivity of 0.28 Btu·in./(h·ft^2·°F),
K = conductivity of proposed material (Btu·in./(h·ft^2·°F)) at 100°F.

Temperature Maintenance Controls (§ 7.4.4.2)
The Standard requires automatic circulation-pump controls that are capable of shutting off the pump when hot water is not required. There are primarily three forms of controls that meet this criterion: time switch control; combination time and temperature control; and demand control.

The simplest complying control system is an automatic time switch. This can be either a standalone system or a contact controlled through a central EMS system. Standalone time switches are available with a wide variety of features. The most important of these is the ability to have multiple schedules such as a separate schedule for each day of the week (the seven-day time switch) or the ability to program in holidays (programmable time switches). Most EMS systems will permit the system to operate on a variety of schedules. Time-controlled systems are most appropriate for designs where the hot water usage is fairly constant and predictable. Where hot water usage is not predictable, time-controlled systems tend to waste energy both in terms of the pump and heat loss because they continue to circulate water from the tank according to the programmed schedule, regardless of the demand.

Time and temperature systems improve on the automatic time switch scheme by using a temperature sensor to shut off the pump whenever the return water temperature is hot. The system is allowed to sit idle until the return temperature drops to a predetermined limit. Typical systems will use a 20°F deadband and place the temperature sensor on the return line. These systems reduce line losses 10% to 20% by reducing the average temperature of the fluid in the line.[3] They will reduce pump energy by up to 90% depending on the frequency of hot-water demand.

Demand-controlled systems use flow sensors to sense the draw of water from the system. On smaller systems, the sensor will typically be located on the inlet to the storage tank. On more extensive systems, several flow sensors wired in parallel will be located at each branch off the main loop. On detection of flow, the circulation pump is initiated. The pump can be shut off either through an adjustable interval timer or a temperature sensor located on the return line. Demand-controlled systems will significantly reduce both the line losses and the pump energy.

Circulating Pump Controls (§ 7.4.4.4)
The pumps that charge hot-water storage tanks with remote heaters must be controlled with time controls that limit the operation of circulation pumps after the heater has been shut off. In many systems the pump continues to operate at the end of the heating cycle to cool down the heater.

Table 7-B—Minimum Pipe Insulation Thicknesses for Service Hot-Water Systems

	Minimum Pipe Insulation Thickness
Conductivity at 100°F [Btu·in/(h·ft²·°F)]	0.22 to 0.28 in. (typical of closed-cell foam or fiberglass)
Nominal Pipe Diameter	
1 in. and less	½
1½ in. and larger	1

3. These savings estimates are based on data contained in the *California Residential ACM Approval Manual*, Appendix RG, CEC P400-03-003 ETF, Adopted November 5, 2003

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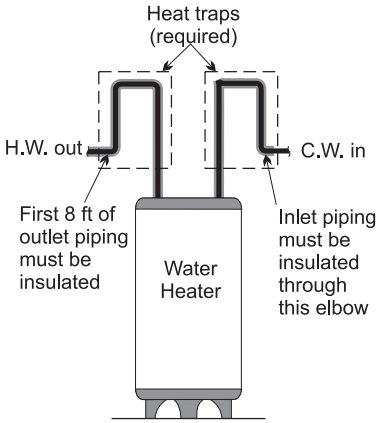

Figure 7-D—Heat Trap and Insulation Requirements for Non-Circulation Systems

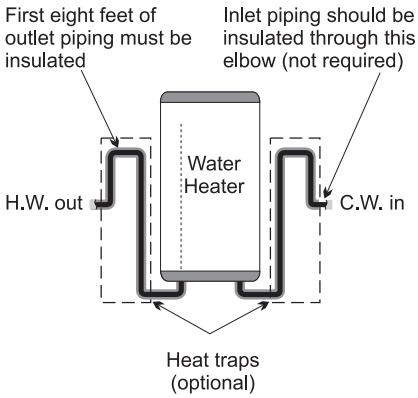

Figure 7-E—Heat Traps on a Tank with Connections on Bottom

The Standard requires these circulating pump controls to provide a maximum of five minutes between the end of the heating cycle and the shutdown of the circulation pump. The supply and return pipes between the hot-water storage tank and the heater must be insulated to the levels required for circulating system piping.

Controls for Heated Pipes (§ 7.4.4.2)
Where heat trace tape or other means are used to maintain water temperatures in the hot water pipes, time controls—as described above for circulation pumps—must be provided. The piping must also be insulated according to the requirements for circulating systems. Heat trace is an alternative to circulating systems to maintain temperature in a DHW distribution system.

Noncirculating Systems (§ 7.4.3 and § 7.4.6)
The losses in noncirculating systems are limited through the use of heat traps to contain the hot water in the storage tank,[4] and use of piping insulation to reduce the wicking of heat out of the tank through conduction. These requirements are depicted in Figure 7-D and described below.

Heat Traps (§ 7.4.6)
A heat trap is a device or arrangement of piping that keeps the buoyant hot water from circulating through a piping distribution system through natural convection. By restricting the flow from the storage tank, standby heat loss is minimized.

Heat traps are required for storage heaters and storage tanks in noncirculating systems with vertical piping. Storage heaters with integral heat traps on both inlet and outlet piping satisfy this requirement. External heat traps must be insulated and should be placed as close as possible to the tank inlet and outlet fittings. Figures 7-D through 7-F depict heat trap configurations for inlet and outlet connections on the top (Figure 7-D), bottom (Figure 7-E) and sides (Figure 7-F) of heaters and storage tanks. In all configurations heat traps can be a 360°

[4]. The heat trap restricts storage tank water from circulating through the piping system through natural convection. This reduces heat loss through the piping system.

Example 7-F—Calculation of Required Insulation Thickness

Q

A designer wants to use cellular glass insulation that has a conductivity of 0.33 Btu·in./(h·ft²·°F) at 100°F. What thickness of insulation is required for a 1-1/2 in. copper (1.625 inch o.d.) hot-water supply line?

A

The conductivity is out of the range of Table 7-B. Therefore, the required thickness has to be calculated. The value of t, the insulation thickness from Table 7-B, is 1 in.

$$T = 1.625\ in. \times \left[\left(1 + \frac{1\ in.}{1.625\ in.} \right)^{\frac{0.33}{0.28}} - 1 \right]$$

$$= 1.23\ in.$$

The insulation on the hot-water supply line must be 1.23 in. (1¼ in.) or thicker.

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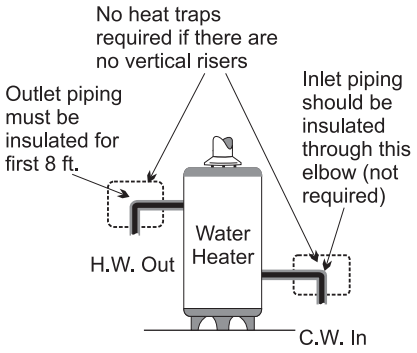

Figure 7-F—Heat Traps on a Tank with Connections on Sides

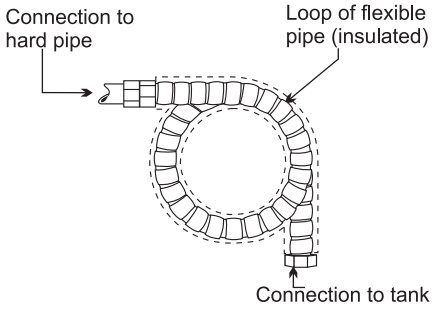

Figure 7-G—Heat Trap through Flexible Pipe Loop

loop of piping (see Figure 7-G), a pre-manufactured device, or some arrangement of piping and elbows that forms an inverted "U" on the tank fittings. Tanks that have horizontal outlets need only a section of vertical pipe that turns downward after leaving the tank (an inverted "L;" see Figure 7-F).

Insulation (§ 7.4.3)
In noncirculating storage systems, the first 8 feet (2.4 m) of outlet piping and the piping between the tank inlet and inlet heat trap must be insulated to the requirements of Table 6.8.3 of the Standard. The required level of insulation is the same as that described in the paragraphs under circulating systems. The same level of insulation is required between the heat traps on both the inlet and outlet side of the tank. Note that distribution piping on a noncirculating system that is heated through heat trace tape or other external means has requirements for controls and insulation as previously described.

Swimming Pools (§ 7.4.5)

In addition to heaters needing to meet the requirements of Table 7.8 for minimum thermal efficiency, there are several requirements for pools.

Restriction on Continuously Burning Pilot Lights (§ 7.4.5.1)
Continuously burning pilot lights are prohibited on natural gas-fired pool heaters. Either a pilotless ignition system or an intermittent ignition system will satisfy this requirement.

Controls (§ 7.4.5.1 and § 7.4.5.3)
There are two types of controls required for each pool heater: an accessible manual on/off switch and an automatic adjustable time switch.

The manual on/off switch must be a dedicated switch or contact. The thermostat setpoint adjustment may not be used to satisfy this requirement. Oil-fired heaters with pilot lights should use either continuously burning pilot lights or pilotless ignition so that occupants do not need to re-light the pilot each time they manually turn the system off. The purpose of these requirements is to encourage the occupants or maintenance personnel to disable the heater when it is not needed. For that reason, the switch must be readily accessible (see definition in § 3) and easy to use.

For pools in public facilities, the manual on/off switch may be in a locked control panel so that it is not accessible to the public. However, facility staff must have access to the control panel at all times.

A time switch must be provided for all pool pumps and pool heaters. Exceptions are provided for pumps that must operate continuously to meet public health standards and pumps that use solar or waste heat recovery to heat the pool. Automatic programmable time switchs will meet the requirements and will help reduce energy costs through automatic control.

Pool Covers (§ 7.4.5.2)
Pools lose heat primarily through three mechanisms: radiation, convection, and evaporation. Of these three, the largest component is generally the evaporation loss, which accounts for 50% to 60% of the overall heat loss in most cases. The Standard requires *all* heated swimming pools to have covers. This applies to pools located either outdoors or indoors. Pool covers must be vapor retardant to reduce evaporation losses.[5]

Pools heated to over 90°F (32°C) must have insulated covers with a minimum insulation value of *R*-12.

[5]. Chapter 49 of the 2003 ASHRAE *Handbook—HVAC Applications* has information on equipment sizing and heat loss from pools.

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Pools that receive over 60% of their energy (computed over an annual operating season) from either heat-recovery or site-solar energy do not need covers. Heat recovered from a pool dehumidification system can be used to meet this requirement. Many pool dehumidification systems have heat recovery for space or water heating as a standard option. Note that the 60% figure refers to the heat required by the pool and is not an indication of the efficiency of the heating source. An analysis consistent with the energy cost budget method (§ 11) should be used to demonstrate the percentage of heating through heat recovery.

Example 7-G—Heat Recovery for Pools, Cogeneration

Q

If a pool is heated through a cogeneration system, are pool covers required?

A

No, since the pool is heated through heat recovery.

Example 7-H—Heat Recovery for Pools, Dehumidification System

Q

An Olympic-size swimming pool receives 80% of its heat (on a yearly basis) through a dehumidification system. Are pool covers required?

A

No, since the pool is heated through heat recovery. If the dehumidification system could only provide 60% of the annual heating load for the pool, either a cover or additional heat recovery from another source would be required.

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Prescriptive Requirements (§ 7.5)

This section only applies to projects that use the prescriptive method of compliance, not to projects that use the Energy Cost Budget (ECB) method of compliance. Regardless of which method is used to demonstrate compliance, all the Mandatory Provisions in § 7.4 must be satisfied.

Combination Space and Water Heating Systems (§ 7.5.1 and § 7.5.2)

Systems that serve both to heat space and water must meet one of three conditions:

- The single space-heating boiler or component of a modular or multiple boiler system that is heating the service water has a standby loss not exceeding:

$$\frac{13.3 \times pmd + 400}{n} \qquad (7\text{-B})$$

pmd is the probable maximum demand in gal/h as determined using standard published procedures (see Table 7-C); and

n is the fraction of the year when the outdoor daily mean temperature is greater than 64.9°F (18.3°C).[6]

- It is demonstrated to the authority having jurisdiction that the combined system will use less energy than separate space and water heating systems. For instance, a designer may provide calculations showing that the addition of a heat exchanger to the space-heating boilers to heat water for a lavatory in a cold climate will use less energy than a dedicated heater due to reduction in standby losses.
- The heater input rating of the combined system is less than 150,000 Btu/h (44 kW).

The standby loss rating in the first condition is to be determined by a 24-hour test performed either at the factory or in the field. Section 7.5.1 specifies that the test shall be conducted with the following conditions: the boiler water shall be maintained at a minimum boiler water temperature 90°F (50°C) greater than the ambient temperature; the ambient air temperature shall be maintained between 60°F (16°C) and 90°F (32°C) throughout the test; and the boiler burner shall only be operated at its minimum input rating. The designer should include the test report with its compliance documents.

Service water-heating equipment used in combination systems must satisfy the minimum performance requirements of § 7.4.2. Space-heating equipment used in combination systems must satisfy the applicable minimum performance requirements of § 6.4.1. The distribution piping, pumps, controls, and terminal devices for service hot water in combination systems must meet all of the requirements of § 7.

These requirements are intended to regulate the use of systems that combine seasonal loads with uniform loads. Energy is wasted in these systems by utilizing an oversized boiler (sized to concurrent space and service water-heating loads) to perform water heating alone after the heating season is over. Systems that combine service water heating with year-round process loads are likely to meet the requirement § 7.5.1(b). (An example of this would be an indirect water-heating bundle in a steam boiler used for steam tables in a commercial kitchen.)

Example 7-I—Standby Loss Calculation for Combination Space and Water-Heating Equipment

Q

What is the standby loss requirement for a combination space- and water-heating system in San Francisco, California, for a 40-unit apartment building?

A

From Table 7-C the pmd is given by:

$$pmd = 40\ units * 10\ \frac{gal}{unit \cdot h} = 400\ gal/h$$

Using hourly TMY data from San Francisco and the procedure outlined in Footnote 6, we find that n=0.65. The standby loss requirement is given by:

$$SL = \frac{13.3 \times pmd + 400}{n} = \frac{13.3 \times 400 + 400}{.65} = 8{,}809\ Btu/h$$

The boiler will comply if it meets the requirements of § 6 *and* it has a standby loss of less than 8,809 Btu/h as determined by a 24-hour test either at the factory or in the field.

6. Unfortunately, this value (n) cannot be found in either Appendix D of the Standard or in ASHRAE *Fundamentals*. It can be calculated from an hourly weather file as follows: 1) Assign a day number (from 1 to 365) to all of the dry-bulb values in an annual hourly (8,760 hr/yr) weather file. 2) Average the outdoor dry-bulb temperatures for each day to create daily mean dry-bulb temperatures. 3) Count the daily mean dry-bulb temperatures that are greater than 64.9°F and *n* is that number divided by 365.

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Systems that are covered by these requirements include:

- Combined hydronic heaters;
- Indirect service water tube bundles in a space-heating water or steam boiler;
- Service water heat exchangers utilizing steam from a space-heating boiler.

Table 7-C—Probable Maximum Demand

Source: Table 6, Chapter 49 of the 2003 ASHRAE *Handbook—HVAC Applications, I-P Edition*

Type of Building	*Maximum Hourly*	*Maximum Daily*	*Average Daily*
Men's dormitories	3.8 gal/student	22.0 gal/student	13.1 gal/student
Women's dormitories	5.0 gal/student	26.5 gal/student	12.3 gal/student
Motels: Number of units[a]			
20 or less	6.0 gal/unit	35.0 gal/unit	20.0 gal/unit
60	5.0 gal/unit	25.0 gal/unit	14.0 gal/unit
100 or more	4.0 gal/unit	15.0 gal/unit	10.0 gal/unit
Nursing homes	4.5 gal/bed	30.0 gal/bed	18.4 gal/bed
Office buildings	0.4 gal/person	2.0 gal/person	1.0 gal/person
Food service establishments			
Type A—full meal restaurants and cafeterias	1.5 gal/max meals/h	11.0 gal/max meals/day	2.4 gal/max meals/day[b]
Type B—drive-ins, grilles, luncheonettes, Sandwich and snack shops	0.7 gal/max meals/h	6.0 gal/max meals/day	0.7 gal/max meals/day[b]
Apartment houses: Number of apartments			
20 or less	12.0 gal/apartment	80.0 gal/apartment	42.0 gal/apartment
50	10.0 gal/apartment	73.0 gal/apartment	40.0 gal/apartment
75	8.5 gal/apartment	66.0 gal/apartment	38.0 gal/apartment
100	7.0 gal/apartment	60.0 gal/apartment	37.0 gal/apartment
200 or more	5.0 gal/apartment	50.0 gal/apartment	35.0 gal/apartment
Elementary schools	0.6 gal/student	1.5 gal/student	0.6 gal/student[b]
Junior and senior high schools	1.0 gal/student	3.6 gal/student	1.8 gal/student[b]

[a] *Interpolate for intermediate values.*

[b] *Per day of operation.*

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Reference

This section reviews definitions, concepts, and calculation methods that are used throughout this chapter.

Boilers
Self-contained low-pressure appliances for supplying steam or hot water. (Low pressure is up to 15 psig for steam and 160 psig for hot water. Anything more is considered high pressure.)

Booster Heaters
Water heaters that raise the water temperature of service hot water for special high-temperature requirements, such as sterilizers or dishwashers.

Energy Factor
A measurement of the combined effects of thermal efficiency and standby losses. It is determined through the DOE test procedure 10 CFR Part 430, Subpart A, which is applicable to the smaller equipment covered by NAECA. The water heater is placed in a controlled environment that is maintained between 65°F and 70°F. The inlet water temperature is maintained at 58°F, and the average tank temperature is maintained at 135°F. The test begins after the heater reaches a stable condition. Over the period of 24 hours, the energy input to the heater is recorded. During the test period, six equal draws of water totaling 64.3 gallons are made at one-hour increments. The energy factor is the ratio of the thermal energy transferred to the water, to the energy input to the heater throughout the test period.

First-Hour Rating
A measure of the combined heater and storage capacity. It is the maximum draw of water that can be obtained from a unit with a fully charged tank without an appreciable drop in outlet temperature. First-hour ratings are used in the selection of residential units.

Heat Traps
Devices or piping arrangements that restrict hot water circulation out of the storage tank through thermal convection currents.

Hot-Water Supply Boilers
Boilers used to heat water for purposes other than space heating. For the purposes of this chapter, they are heaters that meet the temperature and pressure ratings for boilers and that are applied to service water heating systems.

Input-to-Volume Ratio
The input-to-volume ratio of a heater is defined as:

$$\text{Input - to - Volume Ratio} = \frac{Q_{in}}{V}\left(\frac{\text{Btu}}{\text{hr} \cdot \text{gal}}\right) \quad \text{(7-C)}$$

Q_{in} = input rating of the heater (Btu/hr)
V = rated tank volume (gal)

NAECA
The National Appliance Energy Conservation Act of 1987 is a Federal standard that specifies the minimum performance of residential space-heating, space-cooling, and water-heating equipment. For water heaters this includes:

- Electric heaters: all types at or below 12 kW input (including heat-pump water heaters and instantaneous heaters).
- Fuel-fired storage heaters: at or below 75,000 Btu/h input for gas, 105,000 Btu/h input for oil.
- Fuel-fired instantaneous heaters: at or below 200,000 Btu/h input for gas, 210,000 Btu/h input for oil.
- All fuel-fired pool and spa heaters.

Packaged Boilers
Boilers that are shipped complete with heating equipment, mechanical draft equipment, and automatic controls. They may be shipped as a factory-built unit or in multiple sections that are factory built and reassembled on the site.

Point-of-Use Heaters
Water heaters that are located within a few feet of the terminal device or devices that use the hot water. They can be either the instantaneous type or storage type.

Process Energy
The "energy consumed in support of manufacturing, industrial or commercial processes not related to the comfort and amenities of the building's occupants" (§ 3). Examples of process water heating include: hot water used for sterilizing in canning operations; heating of chemical baths in a production facility; and hot water used in the production of pharmaceuticals.

Recirculating Systems
Hot-water distribution systems that circulate hot water through the distribution system either intentionally or unintentionally. Typical circulating systems will be provided with a circulation pump and hot-water return lines.

Thermal Efficiency
Another ratio of the thermal energy transferred to the water to the energy input to the heater. In this case, the heater is initially filled with cold water. The test period extends until the entire volume of water in the heater is fully charged to the design hot-water supply temperature (Source: Chapter 49 of the 2003 ASHRAE *Handbook—HVAC Applications, I-P Edition).*

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Recovery Rate or Recovery Capacity
The rate at which a heater can produce hot water on a continuous basis. This is a measure of capacity used to select water heaters for commercial and industrial systems. The recovery rate of a heater will vary with the temperature range under which it operates. Heaters are typically rated for recovery rates at 80°F, 90°F, and 100°F.

Service Water Heating
Service water heating is defined as heating water for domestic or commercial purposes other than space heating or process requirements (§ 3). Water heating for commercial kitchens, showers, and beauty salons are examples of service water heating.

Terminal Device
A fixture or appliance that uses hot water, such as faucets, dishwashers, and showers.

Thermal Efficiency
The ratio of the thermal energy transferred to the water to the energy input to the heater at a 70°F water temperature rise. It is measured under steady-state conditions with a constant draw of water.

$$E_t(\%) = \frac{Q_{fluid}}{Q_{fuel}} \times 100 \qquad \text{(7-D)}$$

E_t = thermal efficiency.
Q_{Fluid} = heat loss rate.
Q_{Fuel} = heat content rate of the fuel consumed.

Thermal efficiency includes the effects of standby losses. It is measured under specific test conditions.

Water Heater
A heated vessel that provides hot water for a use external to the system.

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Compliance Forms

Compliance forms are provided in the User's Manual to assist in understanding and documenting compliance with the service water heating requirements. Copies of the compliance forms are provided both in printed and electronic form. Modifiable electronic versions are provided on the CD accompanying this Manual, and are also posted on the ASHRAE website for free download.

The service water heating form is organized on one page and in four sections, beginning with header information and mandatory measures and concluding with worksheets for equipment efficiency and combined space and water heaters.

Header Information

Project Name: Enter the name of the project. This should agree with the name that is used on the plans and specifications or the common name used to refer to the project.

Project Address: Enter the street address of the project, for instance "345 Jefferson Street."

Date: Enter the date when the compliance documentation was completed.

Designer of Record/Telephone: Enter the name and the telephone number of the designer of record for the project. This will generally be an architecture firm.

Contact Person/Telephone: Enter the name and telephone number of the person who should be contacted if there are questions about the compliance documentation.

City: The name of the city where the project is located.

Mandatory Provisions Checklist

This section of the compliance form summarizes the Mandatory Provisions for the design of the service water heating system. The mandatory measures are organized on this form in the same order as they are in the Standard. Check the box to indicate that the mandatory requirement applies to the building and that the building complies with the requirement. If the requirement is not applicable, then leave the box unchecked.

Equipment Efficiency Worksheet

Complete a row in this table for each water heater that is to be installed in the building. This list should have the same number of items as the water heater schedule on the plans. For each water heater, enter the system tag. This is the code that is used to identify the equipment on the plans and specifications.

In the second column, enter the equipment type; this should be a choice from Table 7.8 of the Standard. In the third column, enter the subcategory or rating condition from Table 7.8. In the fourth column, enter the input rating for the equipment. Enter the tank volume in the fifth column.

Column six compares the rated efficiency of the equipment with the requirement from the Standard. For small water heaters (those covered by NAECA), the energy factor (*EF*) will be entered. Otherwise, the thermal efficiency (*Et*) should be entered. The efficiency of the equipment must be greater than or equal to the required efficiency in order to comply. The required energy factor or thermal efficiency is taken from Table 7.8 of the Standard.

Column seven compares the standby loss of the equipment to its requirement. This is used only for large water heaters that are not covered by NAECA. The required standby loss is taken from Table 7.8 of the Standard. The proposed standby loss is taken from test data for the water heater.

Combination Space and Water Heating Worksheet

This section only needs to be completed if the project is complying through the Prescriptive Method.

Complete a row in this table for each combination space and water heating system that is to be installed in the building. This list should be a subset of the boilers that are scheduled on the plans. For each combination system, enter the boiler tag. This is the code that is used to identify the equipment on the plans and specifications. For each system the user must demonstrate compliance by filling in the data for either column two, three, or four.

Column two compares the rated stand-by loss of the equipment with the requirement from the Standard. The required stand-by loss must be computed from the probable mean demand (*pmd*) and the fraction of the year when the outdoor daily mean temperature is greater than 64.9°F using the formula in § 7.5.2 of the Standard.

Column three compares the annual energy usage of the combined equipment to the annual energy usage of separate space and water heaters. For each entry in this column, the user must provide supporting calculations demonstrating how the annual energy usage numbers were derived.

Column four demonstrates the input rating of the space heating boiler is less than 150,000 Btu/h. The input rating entered here should match the input rating specified for that boiler in the mechanical schedules.

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Service Water Heating Compliance Documentation

Project Name:	
Project Address:	Date:
Designer of Record:	Telephone:
Contact Person:	Telephone:
City:	

Mandatory Provisions Checklist

- ❑ Load calculations have been provided for sizing of systems and equipment (§ 7.4.1).
- ❑ Equipment efficiencies meet or exceed the requirements of Table 7.8 (§ 7.4.2).
- ❑ Circulating systems are fully insulated (per Table 6.8.3) and have automatic pump controls (§ 7.4.3 and § 7.4.4.2).
- ❑ Non-circulating systems have insulated heat traps and outlet piping insulated (per Table 6.8.3) for 8 ft from the storage tank (§ 7.4.6).
- ❑ Tanks with remote heaters have circulation pump controls (§ 7.4.4.4).
- ❑ All water-heating systems have temperature controls that are adjustable down to 120°F or lower (§ 7.4.4.1).
- ❑ Systems designed with pipe heating systems such as heat trace have temperature or time controls (§ 7.4.4.2).
- ❑ Public lavatories have outlet temperature controls that limit the discharge temperature to 110°F (§ 7.4.4.3).
- ❑ Pool heaters have readily accessible controls and gas-fired heaters do not have standing pilot lights (§ 7.4.5.1).
- ❑ Heated swimming pools have vapor retardant covers (§ 7.4.5.2).
- ❑ Pool heaters and circulation pumps have time switches (§ 7.4.5.3).

Equipment Efficiency Worksheet (§ 7.4.1)

System Tag	Equipment Type (From Table 7.8)	Sub-Category or Rating Condition (From Table 7.8)	Input Rating (Btu/h or kW)	Volume (gal)	Energy Factor or Et		Standby Loss	
					Rated	≥ Required	Rated	≤ Required
						≥		≤
						≥		≤
						≥		≤
						≥		≤

Combination Space and Water Heating Worksheet (§ 7.5.1)

System Tag	Standby Loss Method			or Energy Use Exception (attach calculations			or Size Exception		
	Equipment	≤	Requirement	Equipment	≤	Requirement	Equipment	≤	Requirement
		≤			≤			≤	150,000 Btu/h
		≤			≤			≤	150,000 Btu/h
		≤			≤			≤	150,000 Btu/h
		≤			≤			≤	150,000 Btu/h

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8. Power

General Information (§ 8.1)

General Design Considerations

In § 8 of the Standard, there are three requirements facing the designer of a building's electrical distribution system. These requirements relate to:

- Maximum voltage drop in electrical conductors,
- As-built drawings,
- Operating and maintenance manuals.

These requirements save energy in two ways. First, the voltage drop requirement directly limits power loss in the distribution system. Second, the requirements for single-line drawings and operating and maintenance manuals increases the likelihood that staff personnel will understand the electrical distribution system and that the system will be operated efficiently after it is installed.

Scope

The requirements of § 8 apply to all power distribution systems in buildings that are covered by the Standard (for a review of the Standard's general scope, see Chapter 2 of this Manual).

In the case of alterations to existing facilities, when modifications are made to the electric power distribution system, the requirements of the Standard apply to the components that are being modified or replaced, but not to the entire system. However, when an addition or alteration is made to the system, the voltage drop analysis must include the parts of the existing system extending to the point of electrical supply at the transformer or service entrance equipment.

Inch-Pound and Metric (SI) Units

The Standard is available in two versions. One uses inch-pound (I-P) units, which are commonly used in the United States. The other version uses metric (SI) units, which are used in Canada and most of the rest of the world. The common units for electric power are the same, so the text, examples, and tables in this chapter are appropriate for both sets of units. The only difference is the resistance per length of wire tables. For these, the following conversions may be used.

		I-P Units		SI Units
Length	ft	× 0.3048	=	m
	in	× 25.4	=	mm

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Mandatory Provisions (§ 8.4)

All the requirements in § 8 are mandatory and must always be met, even when the Energy Cost Budget (ECB) method of compliance is used.

Voltage Drop (§ 8.4.1)

The Standard defines two types of conductors:

- *Feeder conductors* run between the service entrance equipment (where the power enters the building) and the branch circuit distribution equipment (e.g., circuit breaker).
- *Branch circuit conductors* run from the final circuit breaker to the outlet or load. In some small buildings, all wiring will be branches running from the main electrical service.

The Standard allows a maximum voltage drop of 2% for feeder conductors and 3% for branch circuit conductors. In practice, these voltage drop limitations result in selecting conductors and conduits based on the practice described in Table 9 of the 2002 *National Electrical Code® Handbook,*[7] which is repeated as Table 8-A. In this table, the voltage drop is dependent on the following:

- Circuit type (single-phase or three-phase);
- Number and size of conductors per phase;
- Conduit types (magnetic or non-magnetic);
- Power factor of the load;
- Circuit length;
- Load current.

Electrical codes may also set minimum wire sizes in some instances. These minimum wire sizes in certain sections of some codes are usually intended to provide practical trade sizes for electricians and to match the short-circuit

Example 8-A—Voltage Drop Calculation, Single-Phase Circuit
(Example adapted from *2002 National Electrical Code® Handbook*)

Q

What is the voltage drop in a 240 volt, two-wire, single-phase heating circuit with a load of 50 amperes? The circuit consists of type THHN copper conductors size 6 AWG, and the one-way circuit length is 100 ft. Does the voltage drop meet the requirements of the Standard?

A

The voltage drop equation for single-phase circuit with 100 percent power factor is:

$$VD = \frac{2 \times L \times Z \times I}{1000} \quad (8\text{-A})$$

VD = voltage drop (based on conductor temperature of 75°F)
L = one-way length of circuit (feet)
Z = conductor effective impedance in ohms per thousand feet (from the *National Electrical Code® Handbook*, Chapter 9, Table 9, repeated as Table 8-A in this manual)
I = load current accounting for power factor (amperes)

For this conductor, the impedance listed in Table 8-A depends on the conduit type (PVC, aluminum, or steel). The impedance also depends on the power factor of the load. Neither the conduit type nor the power factor is specified above. In this case it is reasonable to use the values in the column labeled "Effective Z at 0.85 PF for Uncoated Copper Wires", which is intended to apply to a typical situation. For conduit type, a reasonable assumption is the worst case condition (i.e. steel). Based on these assumptions the impedance is 0.45 ohms per thousand feet.
Substituting values for this example into the equation, the voltage drop is determined to be 4.91 volts.

$$VD = \frac{2 \times 100 \times 0.45 \times 50}{1000} = 4.50 \text{ volts}$$

Next, find the approximate voltage drop expressed as a percentage of the circuit voltage.

$$\text{Percentage voltage drop}_{(\text{line to line})} = \frac{4.50 \text{ volts}}{240 \text{ volts}} \times 100\% = 1.88\%$$

Since the voltage drop on this branch is less than 3%, it meets the requirements of the Standard.

7. *2002 National Electrical Code® Handbook* is a registered trademark of the National Fire Protection Association, Inc., Quincy, MA.

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protection provided by overcurrent devices normally installed for the application. The short-circuit protection is based on the ability of the conductor insulation to withstand fault currents without destructing. The voltage drop requirements in the Standard are presently only a recommendation within the NEC.

There are two types of problems caused by significant voltage drop. First, in most electrical circuits the current increases as voltage at the load drops because the load requires a certain amount of power. When the current increases, there is an increase in the power loss within the conductor that varies as the square of the current. Therefore, the voltage drop is an energy efficiency issue. Second, the voltage drop in the conductors, if excessive, may result in equipment operation problems or equipment failure.

Note that the power requirements of the Standard do not consider power loss in transformers. The output voltage of a transformer will drop as the load increases or as the power factor of the load decreases. Therefore, meeting the voltage drop requirements in the Standard does not guarantee proper equipment operation.

Voltage drop calculations are illustrated in Example 8-A for simple single-phase circuits and Example 8-B for three-phase circuits. For more details refer to the *National Electrical Code® Handbook* published by the National Fire Protection Association.

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Submittals (§ 8.7)

General

This section states that construction documents (drawings and specifications) must include a requirement that the owner receive information about the building's electrical system. The intent of this requirement is to provide the owner with all information that will enable optimal and efficient operation of the building's electrical system. The Standard does not designate the person responsible for providing this information, though the responsibility will normally be assigned to the system installer. The designer is responsible for including these Completion Requirements with the drawings and specifications.

The Standard recognizes that a building official or inspector cannot be expected to check if the owner has received complying documents, but the official does have an opportunity to check that these Completion Requirements are part of the construction documents.

Drawings (§ 8.7.1)

The construction documents must include a requirement that the owner be provided with record drawings of the actual installation within 30 days of system acceptance. These drawings must include:

- A single-line diagram of the electrical distribution system and
- Floor plans showing the location of distribution equipment and the areas served by that equipment.

Manuals (§ 8.7.2)

The construction documents must also include a requirement that the building owner receive manuals that provide instruction about the operation and maintenance of the building's electrical distribution system (see Chapter 6 for similar requirements covering mechanical systems and equipment). The manual must include at least the following information:

- Submittal data stating equipment nameplate rating. The submittal data shall also include optional and accessory installed equipment. The maintenance instructions shall include all installed equipment requiring scheduled maintenance (for example, corrosion prevention) and maintenance due to operating conditions (for example, lubrication as a function of the load and speed). It is essential that product data sheets, photographs, illustrations, examples, and other data be marked to indicate the specific equipment supplied. Where the supplier has product information or operating and maintenance instructions available through electronic media or on computer disks, this should also be provided to the owner.
- Operation manuals and maintenance manuals for each piece of equipment requiring maintenance. Required routine maintenance actions shall be clearly identified.
- Names and addresses of at least one qualified service agency.
- A complete narrative and schematic of the system as it is normally intended to operate. This is essential for the equipment and facility staff to understand the efficient operation of the system.

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Example 8-B—Voltage Drop Calculation, Three-Phase Circuit
(Example adapted from *2002 National Electrical Code® Handbook*)

Q

A 270 ampere continuous load is present on a feeder. The circuit consists of a single 4 in. PVC conduit with three 600 kcmil XHHW/USE aluminum conductors supplied from a 480 volt, three-phase, three-wire source. The conductors are operating at their maximum rated temperature of 75°C. If the power factor is 0.7 and the circuit length is 250 ft, does the voltage drop meet the requirements of the Standard?

A

Step 1: Using Table 8-A, column "X_L (Reactance) for All Wires," select PVC conduit and the row for size 600 kcmil. A value of 0.039 ohms per 1000 ft is given as this X_L. Next, using the column "Alternating-Current Resistance for Aluminum Wires," select PVC conduit and the row for size 600 kcmil. A value of 0.036 ohms per 1000 ft is given for this *R*.
Step 2: Find the angle representing a power factor of 0.7.
Find the arccosine ($\cos^{-1}$) of 0.7, which is 45.57°. For this example, we will call this angle Φ. For step 3, also calculate the sine of 45.57°, which is 0.7141.
Step 3: Find the impedance (Z_c) corrected to 0.7 power factor.

$$\begin{aligned} Z_C &= \left(R \times \cos\Phi\right) + \left(X_L \times \sin\Phi\right) \\ &= \left(0.036 \times 0.7\right) + \left(0.039 \times 0.7141\right) \\ &= 0.0252 + 0.0279 \\ &= 0.0531 \text{ ohms to neutral} \end{aligned}$$

Step 4: Find the approximate line-to-neutral voltage drop.

$$\begin{aligned} &\text{Voltage drop}_{\text{(line-to-neutral)}} \\ &= Z_C \times \frac{\text{circuit length}}{1000 \text{ ft}} \times \text{circuit load} \\ &= 0.0531 \text{ ohms} \times \frac{250 \text{ ft}}{1000 \text{ ft}} \times 270 \text{ amperes} \\ &= 3.577 \text{ volts} \end{aligned}$$

Step 5: Find the approximate line-to-line voltage drop.

$$\begin{aligned} &\text{Voltage drop}_{\text{(line-to-line)}} \\ &= \text{voltage drop}_{\text{(line-to-neutral)}} \times \sqrt{3} \\ &= 3.577 \text{ volts} \times 1.732 \\ &= 6.196 \text{ volts} \end{aligned}$$

Step 6: Find the approximate voltage drop expressed as a percentage of the circuit voltage.

$$\begin{aligned} &\text{Percentage voltage drop}_{\text{(line to line)}} \\ &= \frac{6.196 \text{ volts}}{480 \text{ volts}} \times 100\% \\ &= 1.29\% \end{aligned}$$

Since the voltage drop on this feeder is less than 2%, it meets the requirements of the Standard.

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Table 8-A—Alternating-Current Resistance and Reactance

*for 600-volt Cables, three-Phase, 60 Hz, 75°C (167°F)—Three Single Conductors in Conduit **

Size (AWG or kcmil)	Ohms to Neutral per 1,000 Feet (304.8 meters)														Size (AWG or kcmil)
	XL (Reactance) for All Wires		Alternating-Current Resistance for Uncoated Copper Wires			Alternating-Current Resistance for Aluminum Wires			Effective Z at 0.85 PF for Uncoated Copper Wires			Effective Z at 0.85 PF for Aluminum Wires			
	PVC, Aluminum Conduits	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	
14	0.058	0.073	3.1	3.1	3.1	-	-	-	2.7	2.7	2.7	-	-	-	14
12	0.054	0.068	2.0	2.0	2.0	3.2	3.2	3.2	1.7	1.7	1.7	2.8	2.8	2.8	12
10	0.050	0.063	1.2	1.2	1.2	2.0	2.0	2.0	1.1	1.1	1.1	1.8	1.8	1.8	10
8	0.052	0.065	0.78	0.78	0.78	1.3	1.3	1.3	0.69	0.69	0.7	1.1	1.1	1.1	8
6	0.051	0.064	0.49	0.49	0.49	0.81	0.81	0.81	0.44	0.45	0.45	0.71	0.72	0.72	6
4	0.048	0.060	0.31	0.31	0.31	0.51	0.51	0.51	0.29	0.29	0.30	0.46	0.46	0.46	4
3	0.047	0.059	0.25	0.25	0.25	0.40	0.41	0.40	0.23	0.24	0.24	0.37	0.37	0.37	3
2	0.045	0.057	0.19	0.20	0.20	0.32	0.32	0.32	0.19	0.19	0.20	0.30	0.30	0.30	2
1	0.046	0.057	0.15	0.16	0.16	0.25	0.26	0.25	0.16	0.16	0.16	0.24	0.24	0.25	1
1/0	0.044	0.055	0.12	0.13	0.12	0.20	0.21	0.20	0.13	0.13	0.13	0.19	0.20	0.20	1/0
2/0	0.043	0.054	0.10	0.10	0.10	0.16	0.16	0.16	0.11	0.11	0.11	0.16	0.16	0.16	2/0
3/0	0.042	0.052	0.077	0.082	0.079	0.13	0.13	0.13	0.088	0.092	0.094	0.13	0.13	0.14	3/0
4/0	0.041	0.051	0.062	0.067	0.063	0.10	0.11	0.10	0.074	0.078	0.080	0.11	0.11	0.11	4/0
250	0.041	0.052	0.052	0.057	0.054	0.085	0.090	0.086	0.066	0.070	0.073	0.094	0.098	0.100	250
300	0.041	0.051	0.044	0.049	0.045	0.071	0.076	0.072	0.059	0.063	0.065	0.082	0.086	0.088	300
350	0.040	0.050	0.038	0.043	0.039	0.061	0.066	0.063	0.053	0.058	0.060	0.073	0.077	0.080	350
400	0.040	0.049	0.033	0.038	0.035	0.054	0.059	0.055	0.049	0.053	0.056	0.066	0.071	0.073	400
500	0.039	0.048	0.027	0.032	0.029	0.043	0.048	0.045	0.043	0.048	0.05	0.057	0.061	0.064	500
600	0.039	0.048	0.023	0.028	0.025	0.036	0.041	0.038	0.040	0.044	0.047	0.051	0.055	0.058	600
750	0.038	0.048	0.019	0.024	0.021	0.029	0.034	0.031	0.036	0.040	0.043	0.045	0.049	0.052	750
1000	0.037	0.046	0.015	0.019	0.018	0.023	0.027	0.025	0.032	0.036	0.040	0.039	0.042	0.046	1000

Notes:

1. These values are based on the following constants: UL-type RHH wires with Class B stranding in cradled configuration. Wire conductivities are 100 percent IACS copper and 61 percent IACS aluminum, and aluminum conduit is 45 percent IACS. Capacitive reactance is ignored since it is negligible at these voltages. These resistance values are valid only at 75°C (167°F) and for the parameters as given but are representative for 600-volt wire types operating at 60 Hz.
2. *Effective Z* is defined as $R\ cos(\Theta) + X\ sin(\Theta)$, where Θ is the power factor angle of the circuit. Multiplying *current* by *effective impedance* gives a good approximation for line-to-neutral voltage drop. Effective impedance values shown in this table are valid only at 0.85 power factor. For another circuit power factor (PF), effective impedance (Ze) can be calculated from R and X_L values given in this table as follows:

$Ze = R\ X\ PF + X_L\ sin[arccos(PF)]$

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9. Lighting

General Information (§ 9.1)

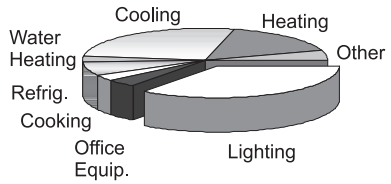

Figure 9-A—Lighting Energy Use Compared to Other Types of Energy Use

Source: U.S. EPA

General Design Considerations

While it varies considerably from building to building, on average, electric lighting accounts for about 35% of commercial building energy consumption in the United States and about 5% of total U.S. energy consumption.[8] Electric lighting directly consumes energy, but for air-conditioned buildings, lighting also generates heat, which adds to the air-conditioning load.

Using efficient lighting equipment and controls is the best way to ensure lighting energy efficiency while maintaining or even improving lighting conditions. For instance, modern fluorescent lighting, such as electronically ballasted T-8 systems, can provide the same quantity of light as older fluorescent lighting while consuming as little as two-thirds of the energy. Similarly, compact fluorescent sources are three to four times more efficient than the traditional incandescent lamps they are designed to replace. Without codes or incentives to encourage energy efficiency, however, the pressure to reduce first costs may lead some designers and builders to install inefficient lighting equipment just because it is less expensive.

In 1992, the Federal Energy Policy Act (EPAct) set minimum efficacy requirements for major classes of lamps. In effect, it eliminated some types of inefficient light sources from the marketplace. EPAct also requires that some classes of luminaires be labeled with the luminaire efficiency rating (LER).

Whereas EPAct addresses the efficiency of lighting components, *Standard 90.1* encourages the use of energy-efficient lighting equipment and design practices by assigning lighting power allowances to both interior and exterior lighting systems. A space or building complies with the Standard when its installed lighting power is less than or equal to the lighting power allowance. This approach promotes design flexibility while ensuring a minimum level of efficiency. In addition, the Standard specifies requirements for lighting controls to prevent lighting use when it isn't needed.

Chapter Organization

This chapter covers the Standard's requirements for interior and exterior lighting systems. The chapter is organized into four main sections.

- The *General Information* section describes the major differences between the new and the old lighting requirements and provides an overview of the scope of the Standard's § 9.
- The *Mandatory Provisions* section describes the specific requirements that always apply to lighting systems, such as requirements for controls and methods for determining luminaire wattage.
- The *Interior Lighting Power* section details the building area and space-by-space methods of determining the maximum lighting power allowance.
- The *Reference* section explains lighting terms and concepts with which a first-time or occasional user of the Standard may be unfamiliar.

Inch-Pound and Metric (SI) Units

The Standard is available in two versions. One uses inch-pound (I-P) units, which are commonly used in the United States. The other version uses metric (SI) units, which are used in Canada and most of the rest of the world. Most of the examples and tables in this chapter use inch-pound units; however, where it is convenient, dual units are given in the text. The SI units follow the I-P units in parenthesis. In addition, the following table may be used to convert I-P units to SI units.

	I-P Units			SI Units
Length	Ft	×	0.3048	m
	In	×	25.4	mm
Area	ft²	×	0.0929	m²
Power Density	W/ft²	×	10.7639	W/m²
Illuminance	lumens/ft² (foot-candles)	×	10.7639	lumens/m² (lux)

[8]. Source: United States Environmental Protection Agency.

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Changes in Lighting Requirements

Section 9 of the 2007 Standard has been modified from previous versions to reflect improvements in lighting technologies and best practices. Compared to the 2004 Standard, the following changes have been made:

- The additional power allowance for spaces with for video display terminals was deleted.
- Additional control requirements were added for display lighting.
- Power allowances for retail display lighting were expanded to include four types of retail sales floor areas.

Scope (§ 9.1.1)

The Standard's lighting requirements apply to new construction of nonresidential and high-rise residential buildings. The Standard also applies to existing nonresidential and high-rise residential buildings, but the lighting requirements for existing buildings are triggered only when 50% or more of the existing luminaires in a space are replaced. A renovation that replaces less than 50% of the existing luminaires in a space is not required to comply with the Standard unless it increases lighting power.

Also, new control devices that directly replace existing control devices must meet some of the Standard's requirements. In particular, the new device may not control more than 2,500 ft² (232 m²) in spaces less than 10,000 ft² (929 m²). For spaces larger than 10,000 ft² (929 m²), each device may not control more than 10,000 ft² (929 m²). In addition, each replacement control must be readily accessible and located so that occupants can see the controlled lighting.

With new buildings as well as additions or alterations, the Mandatory Provisions must always be met. After that, either the building area or space-by-space method may be used to determine the interior lighting power allowance.

Lighting Power Allowance Exemptions

Most lighting power, including interior and exterior lighting systems, is covered by the Standard. However, some lighting for specialized commercial and display purposes, such as outdoor manufacturing, retail display windows, televised sports lighting, theatrical productions, and lighting integral to medical equipment, is exempt and does not need to be considered (see exceptions to § 9.2.2.3). Also exempt are certain lighting systems or portions of systems required for emergency use. Specific lighting systems that are exempt from code requirements are discussed in detail in later sections of this chapter. Note that these are exemptions from the Prescriptive Requirements in § 9.2.2. Designs must still comply with the control requirements and other Mandatory Provisions in § 9.4.

Applying the Standard

For the most part, applying the Standard is relatively simple. However, there are a number of specific cases pertaining to lighting systems where additional information may be helpful in interpreting the Standard requirements.

- *Exterior and Interior Lighting Power Trade-Offs*: The Standard contains separate requirements for exterior and interior lighting systems. Exterior and interior lighting must comply separately with their respective requirements. Trade-offs between the two are not allowed. Trade-offs are allowed only among the exterior lighting applications listed in the Tradable Surfaces section of Table 9.4.5.
- *Calculation Methods for Interior Power Allowance*: There are two ways of determining the interior lighting power allowance: the building area method and the space-by-space method. Both methods may be used in the same building, but trade-offs are not allowed between interior spaces or buildings that use different methods of determining the power allowance.
- *Lighting in Multi-Building Facilities*: Each building in campus-like facilities must comply separately with the interior lighting power requirements, even if multiple buildings are covered under a single building permit. The exterior lighting power allowance, however, applies to the entire site. Trade-offs are allowed only among the exterior lighting applications listed in the Tradable Surfaces section of Table 9.4.5.
- *Lighting in Speculative Buildings*: Speculative buildings are built before the tenants are known. The initial building permit application usually includes just the shell and core with lighting installed only in the building's common areas, such as corridors, toilets, stairwells, and lobbies. Lighting for tenant spaces is provided later as part of the tenant improvements and is often customized for each tenant. Interior lighting power allowance for speculative buildings may be determined by using either the building area or the space-by-space method. Each portion of the building must separately satisfy the Standard's requirements, regardless of the time of tenant occupancy.
- *Lighting in Shell Buildings*: Shell buildings are built before the building's use is known. The space could become light manufacturing, office, warehouse, or any other use depending on the tenant's requirements. In shell buildings, the lighting system is rarely installed before the space is leased. Leasing a building to a tenant effectively defines its use and allows for a determination of the interior lighting power allowance. If a permit applicant wishes to install some lighting in a shell building before the building's use is

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known, the most restrictive (i.e., the lowest) lighting power density should be chosen.

- *Garages and Parking Areas*: A covered garage is treated as interior space and is included as part of the interior adjusted lighting power, which is a maximum of 0.3 W/ft² (Table 9.5.1). Open parking lots (including rooftop parking) are covered by the exterior lighting requirements, which is a maximum of 0.15 W/ft² (Table 9.4.5).

Example 9-A—Application of Standard to Tenant Spaces

Q

The core and shell of a high-rise office building was completed before the Standard's effective date. The construction included the building envelope, the base HVAC system, and lighting for the common areas only. Lighting improvements for each tenant space will be made on a tenant-by-tenant basis when each space is leased.

Tenant spaces on two floors of the building remain empty and unimproved until they are leased a year after the Standard takes effect. At this time, the tenant files a permit application for the construction of a lighting system along with other tenant improvements. Does the Standard apply to the design of the lighting system?

A

Yes. The first tenant improvements in a building are considered new construction, and the lighting Standard applies. Either the whole building or the space-by-space method may be used.

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Compliance Procedure

The following steps provide a methodology for achieving compliance with the requirements of this chapter.

Step 1
Determine if the building under consideration and its associated lighting systems needs to comply (§ 9.1.1).

Step 2
Meet the Mandatory Provisions (§ 9.4) for automatic lighting shutoff (§ 9.4.1.1), space control (§ 9.4.1.2), exterior lighting control (§ 9.4.1.3), additional controls (§ 9.4.1.4), tandem wiring (§ 9.4.2), and exit signs (§ 9.4.3).

Step 3
Compute the installed interior lighting power of the proposed design (§ 9.1.3), determining luminaire wattages in accordance with § 9.1.4.

Step 4
Compute the interior lighting power allowance (§ 9.2.2.3), using either the building area method (§ 9.5), or the space-by-space method (§ 9.6). The space-by-space method is required if the ECB Method is being used for overall compliance.

Step 5
If the space-by-space method has been used, determine if an increase in the interior lighting power allowance is permitted for certain applications (§ 9.6.2).

Step 6
Confirm that the installed interior lighting power (Step 3) does not exceed the interior lighting power allowance (Steps 4 & 5).

Step 7
Determine if the exterior building grounds luminaries meet the efficacy requirements (§ 9.4.4).

Step 8
Determine if the exterior building lighting power meets the allowances specified (§ 9.4.5).

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Mandatory Provisions (§ 9.4)

The Mandatory Provisions apply in all cases, even when the energy cost budget (ECB) method is used for compliance. The Mandatory Provisions require automatic control for buildings larger than 5,000 ft² (465 m²), some type of control in each enclosed space to control interior lighting, and separate controls for special lighting applications such as retail display lighting. The Mandatory Provisions also prescribe methods for calculating interior and exterior lighting power and address other issues such as tandem wiring of two-lamp ballasts, exit signs, and exterior lighting sources.

Lighting Control (§ 9.4.1)

Automatic Lighting Shutoff (§ 9.4.1.1)
Buildings larger than 5,000 ft² (465 m²) must have an automatic control device that is capable of turning off lighting in all spaces without occupant intervention. The automatic control can operate based on a time schedule or by sensing occupants in the space. (See Lighting Controls in the Reference section of this Manual for a description of time-scheduling and occupant-sensing lighting control technologies.)

Time-Scheduling Devices
If time scheduling is used to provide automatic shutoff, the control must be able to accommodate separate schedules for each floor of the building, and for every 25,000 ft² (2,323 m²) space. For instance, a three-story building would need to be capable of controlling the lights on a separate schedule for each floor. In addition, if one of the floors took up 27,000 ft² (2,508 m²), the building would also need to have the capability of controlling the lights on two separate schedules for that one floor. This requirement applies to all buildings, but is especially important for multi-tenant office buildings where each tenant may keep different business hours.

The Standard does not specify details on the type of scheduling control that is required. However, the prudent designer will choose a control that permits scheduling detail appropriate for the intended use of the space or building. For instance, an office operates for different hours on weekdays, Saturdays, Sundays, and holidays. Restaurants may be open late on Friday and Saturday nights, but closed on Mondays. Some retail stores may be open for the same hours every day of the year, whereas other retail stores may be open late one night during the week, close early on Saturday night, and open later on Sunday morning. An appropriate scheduling control should be capable of knowing the type of day (weekday, etc.) and using an appropriate lighting schedule for that day type.

In many spaces, occupants or users of the space need to be able to override the scheduling control. An office worker staying late to prepare an important presentation would be highly inconvenienced if all the lights shut off at 6:00 p.m. with no means to override the control. Section 9.4.1.2(b) of the Standard requires local override capability. Local override can be provided by conveniently located switches, by a telephone system, by local area network (LAN) computer connections, or by other appropriate means. When possible, the local override should energize the lights only in the area where they are needed and in all common areas, hallways, and lobbies required to exit the area. The Standard limits the maximum area for override to an entire floor or to 25,000 ft² (2,323 m²), whichever is less. Smaller override areas are recommended for most lighting designs. These requirements are explained in more detail in the section on Space Control.

Occupant-Sensing Devices
Occupant-sensing devices are an alternative to scheduling controls and an acceptable means of meeting the requirement for automatic shutoff. The designer is free to arrange occupant-sensing controls in any manner that makes sense for the building design. In office spaces, each room or space might have an occupant sensor. Of course, the smaller the area controlled, the greater the energy savings will be. In open office areas, several occupant sensors may be connected so that the lights remain on if any one of the sensors detects occupants. However, in order to satisfy the requirement, it is necessary that all the general lighting be controlled by one or more occupant sensors. In addition, the occupant sensor must turn off the lights in each controlled space within 30 minutes of the last occupant detection.

Some buildings, such as hotel lobbies, or never-close supermarkets, always have the lights on. The Standard does not require automatic shutoff for spaces intended for 24-hour operation. A few other areas are also exempt from § 9.4.1.1 automatic control requirements: spaces where patient care is rendered and spaces where automatic shutoff would endanger the safety and security of the room or building occupants. Example spaces might be an elevator machinery room or a patient examination room.

Space Control (§ 9.4.1.2)
Each room or space enclosed by ceiling-height partitions must have at least one device to control the general lighting within the space independently from the rest of the building. The control device can be an occupant sensor, a manual

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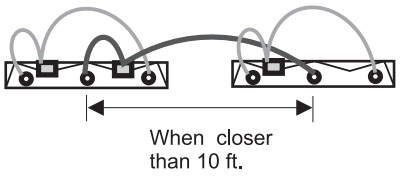

Figure 9-B—Tandem Wiring of Electromagnetic Ballasts

switch, or another type of lighting control technology.

In classrooms, conference/meeting rooms, and employee lunch/break rooms the control device shall be an occupancy-based automatic control that turns the lights off within thirty minutes of all occupants leaving the space. These spaces are not required to be connected to other automatic lighting shutoff controls. This requirement does not apply to spaces with multi-scene control, shop classrooms, laboratory classrooms, and preschool through twelfth grade classrooms.

Lighting controls shall be readily accessible to personnel occupying or using the space. This means that the lighting controls must be visible to occupants, easy to get to, and easy to operate. The control can be situated in a remote location only when necessary for reasons of safety or security (see exception to § 9.4.1.2). When installed in a remote location, the control device must have an indicator light that is part of the control or located in close proximity to the control. In addition, the control must be clearly labeled to identify which lighting it controls.

Large rooms or spaces may need more than one control because the Standard places limits on the maximum area that can be controlled by a single switch or control. For spaces that are 10,000 ft² (929 m²) or smaller, each control can serve a maximum of 2,500 ft² (232 m²). For spaces larger than 10,000 ft² (929 m²), each control can serve a maximum of 10,000 ft² (929 m²).

Each enclosed space must have a means to override any time-of-day or scheduled automatic shutoff control required in § 9.4.1.1 for no more than four hours. The override control does need to be located within the space it controls, unless it meets the stated exception allowing remote location for reasons of safety or security. The override control does not have to be the same control as required by this section. Override of the automatic shutoff control can be provided in a number of different ways, including computer connections over a local area network (LAN), telephone systems, or other means. For smaller, enclosed spaces, occupancy sensors may prove to be more practical and economical since they meet the requirements for both automatic shutoff and space control.

Exterior Lighting Control (§ 9.4.1.3)
Exterior lighting shall be automatically controlled to turn off the lights during daytime hours and/or when they are not needed in the evening.

If the exterior lighting system is not intended for dusk to dawn operation, then two types of controls may be used: an astronomical time switch or a photosensor in combination with a timeswitch.

For lighting systems intended for dusk to dawn operation, may be controlled either by a photosensor or an astronomical time switch.

All timeswitches used to meet this requirement shall have battery backup, flash memory or other means to retain programming information for at least 10 hours during a loss of power.

Additional Control (§ 9.4.1.4)
Many special lighting applications must be controlled separately, including display lighting in retail stores, case lighting,

Example 9-B—Number of Controls

Q

An open office is 9,000 ft². How many controls are required for this space?

A

Four, since this space is smaller than 10,000 ft². Each space control can serve a maximum area of 2,500 ft² (232 m²).

Q

An open office is 11,000 ft². How many controls are required?

A

Two, since this space is larger than 10,000 ft². Each control can serve a maximum area of 10,000 ft² (929 m²).

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hotel/motel guest rooms, task lighting, non-visual lighting applications, and demonstration lighting. These are discussed below.

Display/Accent Lighting
Lighting used to highlight artwork or merchandise in retail stores, art galleries, lobbies, and other spaces must have a separate lighting control. This additional control can save considerable energy since the hours required for display lighting are generally fewer than the hours that the space is occupied. In a retail store, for instance, employees typically arrive one to two hours before the store opens in order to prepare the store, and often employees need to stay for an hour or two after the store closes. Without a separate control for display lighting, the display lighting would have to be operated for two to four hours each day when it isn't needed. Controls for display lighting can be situated in remote locations, but it is advisable that they have indicator lights and be clearly marked to indicate which lighting is controlled.

Case Lighting
Lighting is frequently installed in closed casework for the display of jewelry and other fine merchandise. Such lighting is required to have a separate control from that used for general illumination of the space. The reason for this requirement is the same as for display lighting: the case lighting is only needed during store hours, not during the entire occupancy period of the space. Usually, the control for case lighting is integral to the case.

Hotel/Motel Guest Room Lighting
A master lighting control is required at the entry door of hotel and motel guest rooms to control all permanently installed luminaires and switched receptacles. The control is usually a three-way device wired in combination with local controls. In multiple-room suites, a single master control must be located at the main entrance. This master lighting control allows guests or the housekeeping staff to turn off all permanently installed luminaires when they are exiting the room.

Task Lighting
All supplemental task lighting in a space shall have a separate control. Desk lamps will inherently meet this requirement, but the requirement also applies to permanently installed under-shelf or under-cabinet lighting. Such lighting can have a switch integral to the luminaires or be controlled by a wall-mounted control device, provided the control device is accessible and the controlled lighting can be observed when the switch is toggled.

Non-Visual Lighting
Lighting needed for non-visual purposes, such as plant growth or food warming, must have a separate control. This is because such lighting is likely to be needed at different times than the general lighting.

Demonstration Lighting
Lighting on display in retail lighting stores and lighting that is being demonstrated in classrooms and lighting education facilities must have a separate control. Again, the justification is that such lighting is operated on a separate schedule from the general lighting.

Tandem Wiring (§ 9.4.2)

A single conventional two-lamp fluorescent ballast (electromagnetic) is more efficient than two separate one-lamp ballasts. The Standard limits the use of one-lamp electromagnetic ballasts by requiring that adjacent fluorescent luminaires use a technique called tandem wiring.

For single-lamp fixtures, this means that every two fixtures share a ballast. For three-lamp fixtures with tandem wiring, every other luminaire has one ballast and every other luminaire has two ballasts. A cable (or whip, it is sometimes called) extends from one luminaire to the next, enabling the luminaire with the extra ballast to provide power to the single lamp in the adjacent luminaire. Figure 9-B shows tandem wiring for two adjacent three-lamp luminaires.

There are several exceptions to the tandem wiring requirement.

- Surface-mounted or pendant-mounted luminaires that are not continuous are exempt.
- Recessed luminaires that are on center spaced more than 10 ft (3 m) are exempt.
- Luminaires that use three-lamp ballasts (either electronic or electromagnetic ballasts) are exempt.
- Luminaires on emergency lighting circuits are exempt.
- Luminaires with no available pair are exempt, e.g., when a room has an odd number of luminaires.
- Luminaires that use a single-lamp, high-frequency, electronic ballast are exempt.

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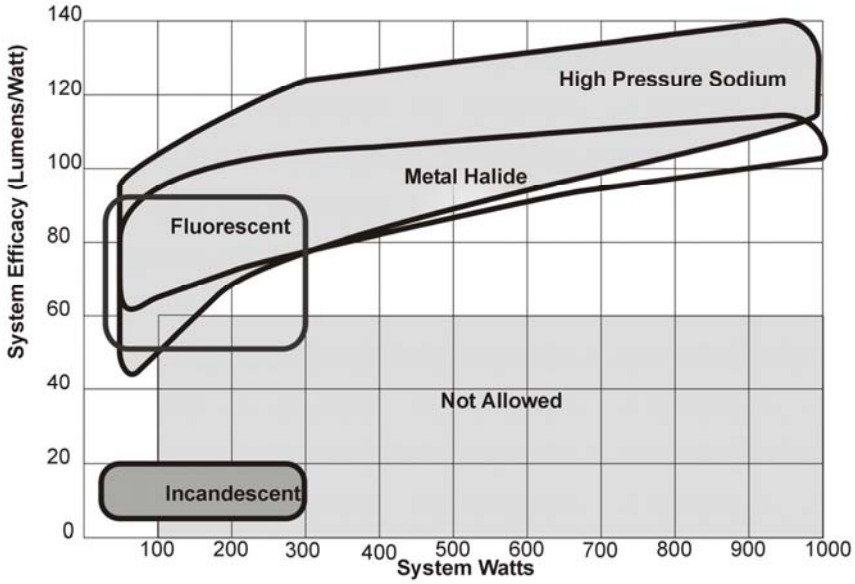

Figure 9-C—Exterior Grounds Lighting and Specific Technologies

Exit Signs (§ 9.4.3)

The Standard requires that internally illuminated exit signs use no more than 5 W per face. Most LED exit signs will meet this requirement. There are other light sources that will also meet this requirement. The selection of any exit sign should also include confirmation that it meets all applicable safety codes.

Exterior Building Grounds Lighting (§ 9.4.4)

Parking lots, pedestrian walkways, gardens, and other landscaped areas associated with a building must have an efficient lighting system. The Standard requires that all exterior building grounds luminaires that operate at more than 100 W have an efficacy greater than 60 lumens/W or be controlled by a motion sensor so that the lights operate for minimal hours.

The efficacy requirement will eliminate the use of all incandescent and mercury vapor discharge sources greater than 100 W in exterior building grounds luminaires. Full-size fluorescent, metal halide, high-pressure sodium, and most other high-intensity discharge (HID) lighting sources will have an efficacy greater than 60 lumens/W. Small luminaires for walkways, exterior stairs, and other applications will typically be smaller than 100 W and will be exempt from the requirement.

Some exterior lighting applications are exempt from the requirement, including traffic signals, lighting within outdoor signs, and lighting used to illuminate public monuments or registered historic landmarks. There is an additional exemption to the lighting efficacy requirement when an occupancy sensor or motion sensor controls the lighting application.

Figure 9-C illustrates the efficacy requirements for exterior grounds lighting and shows the performance range of typical luminaires. The horizontal axis shows the range of system wattages. The vertical axis shows system efficacy range in lumens per watt. The boundaries of typical available products are shown for high-

Example 9-C—Accessibility of Lighting Controls

Q

Can the lighting controls for public corridors in a mall be physically grouped and switched from a remote location?

A

Yes, because of security reasons. In addition, by switching from a remote location, any unusual appearance or functional discrepancy caused by partial lighting can be avoided. The remote control must have an indicator light and must be clearly marked to indicate which lighting it controls. Note that "grouping" refers to the physical placement in the same area of a number of individual controls. There is no reduction allowed in the number of controls required.

Q

Do lighting controls in airports, building lobbies, banks, libraries, and department stores need to be accessible?

A

No, there is an exception to the accessibility requirement for safety and security reasons. The remotely located control must have an indicator light and must be clearly marked to indicate which lighting it controls.

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pressure sodium (HPS) luminaires, metal halide luminaires, incandescent luminaires, and compact fluorescent luminaires. This figure shows that typical high-pressure sodium and metal halide luminaires have an efficacy well above the required 60 lumens/W. The only HPS luminaires that might not meet the requirement are those with small lamps (just over 100 W). Most fluorescent lamps also meet the requirement, especially those with electronic ballasts. Common incandescent luminaires have an efficacy less than 20 lumens/W; if they are larger than 100 W they would not meet the requirement.

Exterior Building Lighting Power (§ 9.4.5)

The Standard specifies power limits for many exterior lighting applications including parking lots, walkways and plazas, building entrances and exits, canopies and overhangs and outdoor sales areas. For these applications, an exterior lighting power allowance is calculated for the entire project and a lighting budget is established.

Additional power allowances are provided for other lighting applications such as building facades, automatic teller machines, guard stations, drive through windows and parking near retail establishments, but these are use-it-or-lose-it allowances and no tradeoffs are permitted. There is a 5% adder that may be applied to the exterior lighting power allowance.

The lighting power allowances are shown in Table 9-A, which is the same as Table 9.4.5 from the Standard.

Certain types of exterior lighting applications are specifically exempt when they are equipped with an independent control. These include the following:

- Specialized signal, directional, and marker lighting associated with transportation are exempt. These include traffic signals, directional signs, and other similar luminaires.
- All lighting within advertising signs is exempt. This includes pole-mounted or building-mounted signs as long as the lighting is integral to the sign. The exemption does not apply to building-mounted signs that are illuminated by luminaires positioned outside the sign and directed toward the sign.
- Lighting that is integral to equipment or instrumentation and is installed by its manufacturer;
- Lighting used for theatrical purposes, including performance, stage, film production and video production;
- Lighting for athletic playing areas;
- Temporary lighting;
- Lighting for industrial production, material handling, transportation sites, and associated storage areas;
- Lighting for theme elements in theme/amusement parks; and
- Lighting used to highlight features of public monuments and registered historic landmark structures or buildings. To qualify as historic, a monument or building must be specifically designated as historically significant by the adopting authority or listed in "The National Register of Historic Places." It may also be

Table 9-A—Lighting Power Limits for Building Exteriors

(This is Table 9.4.5 in the Standard)

	Application	Power Allowance
Tradable Surfaces (Lighting Power Densities for uncovered parking areas, building grounds, building entrances and exits, canopies and overhangs, and outdoor sales areas may be traded.)	**Uncovered Parking Areas**	
	Parking Lots and drives	0.15 W/ft²
	Building Grounds	
	Walkways less than 10 feet wide	1.0 Watts/linear foot
	Walkways 10 feet wide or greater, Plaza areas and Special feature areas	0.2 W/ft²
	Stairways	1.0 W/ft²
	Building Entrances and Exits	
	Main Entries	30 Watts/linear foot of door width
	Other doors	20 Watts/linear foot of door width
	Canopies and Overhangs	
	Canopies (free standing, attached & and overhangs)	1.25 W/ft²
	Outdoor Sales	
	Open areas (including vehicle sales lots)	0.5 W/ft²
	Street Frontage for vehicle sales lots in addition to "open area" allowance	20 Watts/linear foot
Non-Tradable Surfaces (Lighting Power Density calculations for the following applications can be used only for the specific application and cannot be traded between surfaces or with other exterior lighting. The following allowances are in addition to any allowance otherwise permitted in the Tradable Surfaces section of this table.)	Building Facades	0.2 W/ft² for each illuminated wall or surface or 5.0 Watts/linear foot for each illuminated wall or surface length
	Automated Teller Machines & Night Depositories	270 watts per location plus 90 watts per additional ATM per location
	Entrances and Gatehouse Inspection Stations at guarded facilities	1.25 W/ft² of uncovered area (covered areas are included in the Canopies and Overhangs section of Tradable Surfaces)
	Loading Areas for Law Enforcement, Fire, Ambulance and other Emergency Service Vehicles	0.5 W/ft² of uncovered area (covered areas are included in the Canopies and Overhangs section of Tradable Surfaces)
	Drive-up Windows at Fast Food Restaurants	400 watts per drive-through
	Parking near 24-hour Retail Entrances	800 watts per main entry

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exempt if the U.S. Secretary of the Interior determines that the monument or building is eligible for listing in the Register.

The 5% Adder

The Standard allows an additional 5% of power to be used for any of the tradable or non-tradable exterior lighting applications. The power allowance for tradable and non-tradable lighting power applications is summed and 5% of this total may be allocated to supplement the power budget for any of the exterior lighting allowances.

Determining Exterior Building Lighting Power Compliance

Determining whether a building complies with the exterior building lighting power requirements is a two-step process. The first step is to calculate the exterior lighting power allowance (ELPA) for the tradable exterior lighting applications. The ELPA is calculated by multiplying each lighted area or width of door opening by the appropriate exterior lighting unit power allowance.

The second step is to calculate the exterior connected lighting power (CLP) of the proposed design. The exterior CLP is determined by totaling the exterior lighting power for all proposed exterior luminaires that are not exempt from the exterior lighting requirements. When determining input wattage for luminaires, it is important to include ballast losses for all fluorescent and HID sources. The input wattage tables in the Reference section of this chapter may be used to calculate CLP of specific light sources if luminaire manufacturer data are unavailable.

The project complies with the exterior building lighting requirement if the exterior CLP is less than or equal to the ELPA. Trade-offs are not allowed between the exterior lighting systems and any other building systems, including interior lighting systems. However, for multi-building facilities, the ELPA applies to the entire site. Thus, trade-offs are permitted between different *exterior* lighting systems on the site, provided the total exterior CLP does not exceed the total ELPA.

Example 9-D—5% Adder for Exterior Lighting

Q

An office building has a 40,000 ft² lighted parking lot and a 3,500 ft² lighted façade. The installed power for the parking lot is 6 kW and the installed power for the façade is 1 kW. Does this project comply with the exterior lighting power limits of § 9.4.5?

A

Yes. The parking lot complies because the allowance is 0.15 W//ft² times the area of 40,000 ft² and this product is 6 kW, which is exactly equal to the installed power, so the parking lot by itself complies. The façade lighting allowance is 700 W (0.20 W/ft² times the 3,500 ft² area). The 1,000 W of installed power exceeds the allowance, however, an additional 5% of the total allowed power of 6,000 W plus 700 W can be allocated among the lighting applications. The 5% adder is 5% of 6,700 W or 335 W.

Since none is needed for the parking lot (it complies without the adder), the entire 5% adder may be applied to the façade lighting. When this is added to the basic allowance of 700 W the adjusted allowance is 1,035 W, which is greater than the 1,000 of installed façade lighting.

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Interior Lighting Power

The prescriptive lighting requirements limit the installed electric wattage for interior building lighting. The Mandatory Provisions discussed in the previous section must be met in all instances, but some of the Prescriptive Path requirements are subject to trade-offs when the Energy Cost Budget (ECB) method is used for compliance. In other words, more power can be used for lighting if other building systems are made more efficient. The opposite is also true. A more efficient lighting system, for example, might permit a less efficient HVAC system.

The prescriptive lighting requirements are one of the most important features of the Standard. As with the other sections of the Standard, however, these lighting requirements are minimum requirements. Designers working on specific projects may often be able to design more efficient lighting systems.

There are two ways to determine the interior lighting power allowance. The building area method (§ 9.5) is the easiest method and is appropriate for an entire building or an entire occupancy in a multi-occupancy building. The space-by-space method accounts for specific lighting applications and can distinguish, for instance, between various types of seating areas in an auditorium.

Often, separate permit applications are filed for the lighting systems serving different occupancies in multi-occupancy buildings. In these cases, each building occupancy must separately comply with the requirements. When a single permit application includes the lighting systems for more than one occupancy, it is possible to make trade-offs between the occupancies. However, these trade-offs are possible only when both occupancies use the same method to determine the lighting power allowance. If one occupancy uses the space-by-space method and the other occupancy uses the building area method, then trade-offs are not permitted.

Note that these lighting allowances apply regardless of whether a space, such as a warehouse, is heated or unheated. Also, be aware that covered parking garages are included in the interior lighting category.

Exempt Interior Lighting

Most interior lighting, including both permanent and portable luminaires, must be included in the calculations of installed lighting power. However, certain specialized lighting is exempt. Exempt lighting can be ignored when determining the installed lighting power for comparison against the lighting power allowance. Exempt lighting must be independently controlled. The following types of lighting applications and equipment are exempt:

- Display or accent lighting that is essential to the function performed in galleries, museums, and monuments;
- Lighting that is integral to equipment or instrumentation and is installed by its manufacturer;
- Lighting specifically designed for use only during medical or dental procedures and lighting integral to medical equipment;
- Lighting integral to both open and glass-enclosed refrigerator and freezer cases;
- Lighting integral to food warming and food preparation equipment;
- Lighting for plant growth or maintenance;
- Lighting in spaces specifically designed for use by persons with special lighting needs, including visually impairment, and other medical and age related special needs;

Example 9-E—Interior Lighting Power Allowance, Building Area Method

Q

The lighting system for an office building is constructed in phases. The lighting systems for the entrance lobby, the toilets, and other common building areas are included with the plans and specifications for the base building. As tenants move into the building, the tenant improvement plans will include the lighting system for each tenant space. Can the building area method be used for the base building lighting system? What about the tenant lighting systems?

A

The building area method may be used for either the tenant spaces or the base building when separately metered or permitted.

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- Lighting in retail display windows, provided the display area is enclosed by ceiling-height partitions;
- Lighting in interior spaces that have been specifically designated as registered interior historic landmarks;
- Lighting that is an integral part of advertising or directional signage;
- Exit signs;
- Lighting that is for sale or lighting educational demonstration systems;
- Lighting for theatrical purposes, including performances and stage, film, and video production;
- Lighting for television broadcasting in sporting activity areas;
- Casino gaming areas.
- Furniture mounted supplemental task lighting that is controlled by automatic shutoff and shall have a control device integral to the luminaire or a nearby wall mounted control device (§9.4.1.4(d)).

While the lighting power for these applications is exempt, the control and efficacy requirements in the Mandatory Provisions section still apply.

Portable Lighting

Although the designer cannot prevent users from plugging in portable lighting of their own choosing, the designer must account for portable lighting intended for the space, such as furniture-mounted task lights and lighting in permanent displays. Even if the designer of the project is not responsible for specifying portable lighting, the calculations should include an allowance for the expected use of this equipment if its consideration is included in the design.

Building Area Method (§ 9.5)

The building area method is the easiest way of determining the lighting power allowance. In the case of an office, the whole building allowance, as shown in Table 9-B, is 1.0 W/ft².

The building area method assigns a single interior lighting power density in W/ft² based on the building type. The lighting power density is multiplied by the gross lighted area (see the Reference section) of the building to determine the interior lighting power allowance (ILPA).

Some of the building types in Table 9.5.1 (Table 9-B in this document) require some clarification.

Dining

There are three building types labeled dining: Bar Lounge/Leisure, Cafeteria/Fast Food, and Family. Most of the time, the distinction will be clear. Family dining is characterized by table service, menus, etc. Much of the lighting in the dining area is provided by incandescent sources, often on dimmers. Cafeteria/Fast Food dining has no table service; patrons order and pick up their food from a counter and then go to a table. Bar Lounge/Leisure has a very limited food menu. The atmosphere is more social with a great deal of interaction among patrons. Often pool tables, game machines, TV monitors, a stage, or other means of entertainment is offered. When the building type for dining is not clear, the authority having jurisdiction will decide.

Religious Building

This building type applies to a religious building with a sanctuary. It also includes offices, meeting rooms, and other support facilities within the building. If other buildings exist on the site, such as schools, major libraries, or administration buildings, these should be considered as separate building types.

Gymnasiums and Exercise Centers

An exercise center is characterized by exercise machines and workout areas, while a gymnasium is a larger space with a high ceiling suitable for basketball or other team sports.

Table 9-B—Lighting Power Densities Using the Building Area Method

(This is Table 9.5.1 in the Standard)

Building Area Type	*W/ft²*	*Building Area Type*	*W/ft²*
Automotive Facility	0.9	Multi-Family	0.7
Convention Center	1.2	Museum	1.1
Court House	1.2	Office	1.0
Dining: Bar Lounge/Leisure	1.3	Parking Garage	0.3
Dining: Cafeteria/Fast Food	1.4	Penitentiary	1.0
Dining: Family	1.6	Performing Arts Theater	1.6
Dormitory	1.0	Police/Fire Station	1.0
Exercise Center	1.0	Post Office	1.1
Gymnasium	1.1	Religious Building	1.3
Healthcare-Clinic	1.0	Retail	1.5
Hospital	1.2	School/University	1.2
Hotel	1.0	Sports Arena	1.1
Library	1.3	Town Hall	1.1
Manufacturing Facility	1.3	Transportation	1.0
Motel	1.0	Warehouse	0.8
Motion Picture Theater	1.2	Workshop	1.4

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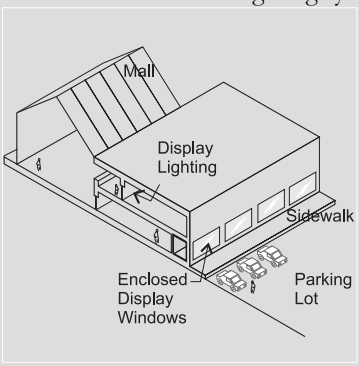
Office
This building type applies to administration buildings, multi-tenant offices, and other similar facilities. Office space is common to just about all the building types listed in Table 9.5.1 (Table 9-B in this document), but this supplementary space was accounted for when the power allowances for the other building types were developed. The office building type should only be used for buildings where offices are the primary use.

Example 9-F—Exempt Interior Lighting, Retail Store Windows

Q

A proposed retail store in a mall will have display windows on the parking-lot (exterior wall) side and windows on the mall (interior) side. The parking-lot side window displays will be closed off from the store interior, but the displays on the mall side are directly accessible from inside the store. Is either of these lighting systems exempt?



A

All display lighting in the windows on the parking-lot side is exempt because the display area is enclosed by ceiling-height partitions. However, display on the mall side of the store is not exempt because it is visually connected to the sales area of the store. While the display lighting in the enclosed show window (parking-lot side) is exempt from the lighting power requirements, it still must have a separate control (see the Mandatory Provisions). Display lighting that is intermingled in the sales area must also have a separate control.

Example 9-G—Exempt Interior Lighting, Laboratory Test Lights

Q

A medical laboratory is studying the effect of lighting on a chemical process. Ordinary fluorescent luminaires are arranged over the test bench and connected to timers. This lighting is separate and distinct from general lighting used throughout the laboratory. Is either the general lighting or the test lighting exempt?

A

The general lighting is covered by the Standard. The test lighting is exempt. However, the test lighting should be installed in a manner consistent with the permanence of the experiments: if experiments are temporary, then the lighting should not be recessed or otherwise installed in a relatively permanent fashion. The Mandatory Provisions require a separate lighting control for nonvisual lighting. The lighting arranged for the test is non-visual, since its purpose is to affect a chemical process, not to enable human sight. The lighting arranged for the test must therefore have a separate control.

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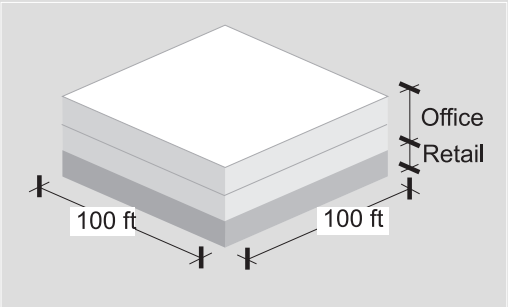
Example 9-H— Interior Lighting TradeOffs Within a Building



Q

A 30,000-ft² building has retail on the ground level and offices on the second and third levels. Can the designer make trade-offs between interior lighting in the retail and office areas? In other words, if the designed lighting power density in the retail area is 1.6 W/ft² and the designed lighting in the office areas is 0.9 W/ft², will the building comply with the requirements?

A

The designer can make trade-offs between the interior lighting for the two occupancies as long as one electrical permit is issued for both the office and retail lighting systems. The lighting power allowance is 35,000 W (1.17 W/ft²) as shown in the following calculation.

$$Allowance = (10{,}000 \times 1.5) + (20{,}000 \times 1.00) = 35{,}000$$

$$Lighting\ Power = \frac{35{,}000}{30{,}000} = 1.17 W / ft^2$$

The installed lighting power of the proposed building is 34,000 W, which is less than the allowance.

$$Installed = (10{,}000 \times 1.6) + (20{,}000 \times 0.9) = 34{,}000$$

$$Lighting\ Power = \frac{34{,}000}{30{,}000} = 1.13 W / ft^2$$

If the lighting systems for the retail and office portions of the building are constructed under separate electrical permits (which is the more likely scenario), then each building occupancy would have to independently comply with the lighting requirements and no trade-offs would be permitted between them.

Q

In the previous example, suppose that the interior lighting systems for the retail and office portions of the building are included on the same electrical permit application. Is it possible to use the space-by-space method for the retail portion and the building area method for the office portion?

A

This is permitted, although it would not be possible to make trade-offs between the office and retail areas since different methods were used to determine the interior lighting power allowance.

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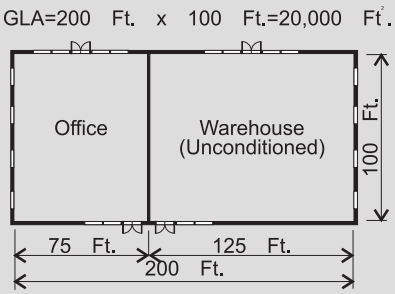
Example 9-I—Interior Lighting Power Allowance, Building Area Method

Q

A one-story building measures 200 ft by 100 ft and consists of an office and an unconditioned warehouse. The building has 12 in.-thick exterior walls. The partition that separates the office and the warehouse is 8 in. thick. The office area is 75 ft by 100 ft measured from the outside edge of the exterior walls to the center of the partition wall. The warehouse is 125 ft by 100 ft measured from the outside edge of the exterior walls to the center of the partition wall. What is the gross lighted area? What is the interior lighting power allowance using the building area method?



A

Gross lighted area is measured to the outside surface of exterior walls and to the centerline of interior partitions. The gross lighted area of the entire building is 100 ft x 200 ft = 20,000 ft². The gross lighted area of the office portion is 7,500 ft² and for the warehouse is 12,500 ft². The interior lighting power density for the office portion of the building is 1.0 W/ft² and the density for the warehouse portion is 0.8 W/ft².

$$\textit{Lighting Power Allowance} = (1.0 \times 7{,}500) + (0.8 \times 12{,}500) = 17{,}500\text{W}$$

Provided the interior lighting system for the entire building is included under the same permit application, the designer can use more lighting power in the office and less in the warehouse, as long as the overall interior lighting power is less than 17,500 W.

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Space-by-Space Method (§ 9.6)

The space-by-space method is the second of the two methods for determining interior lighting power allowance (ILPA). This approach offers greater flexibility and is applicable for all building types; however, it requires a little more effort. Rather than looking up the lighting power allowance for the entire building, the lighting power allowance is determined separately for each space within the building and then summed. Even though the designer must develop lighting that works in each space, it may be simpler for code compliance purposes to use the building area method.

If the space-by-space method is used for one portion of a multi-occupancy building and the building area method is used for another, then trade-offs are not permitted between the two building occupancies. In this case, each building occupancy must comply separately.

The space-by-space allowances are included in Table 9.6.1 of the Standard. and some common spaces are shown in Table 9-C.

However, the allowance for some space types, such as corridors, can vary considerably from a low of 0.5 W/ft² for corridors in manufacturing buildings to a high of 1.0 W/ft² for corridors in hospitals and health care facilities. Similarly, there is a big variation for dining areas, active storage, auditoriums, and lobbies. These differences account for the varying lighting conditions, the typical lighting equipment used in the different space types, and other considerations.

In addition to the common space types, Table 9.6.1 has space types that are unique to each building type. For instance, a courthouse has space types for a courtroom, confinement cells, and judges' chambers. These space types are unique to a courthouse and may only be used for courthouses.

Space types are eligible for additional power allowances for decorative lighting, retail display lighting, and areas with visual display terminals.

The process is to divide the gross lighted area of the building into each of the space types. The lighting power allowance for each space type is the area of that space type multiplied by the lighting power density for that space type. The allowance for the whole building is the sum of the allowances for each of the applicable space types. Example 9-J illustrates how to determine the lighting power allowance using the space-by-space method.

Most of Table 9.6.1 is unambiguous; however, a few of the common space types and building specific space types need some explanation.

Table 9-C—Common Space Types for Space-by-Space Method

Space Type	*W/ft² Range*	*Space Type*	*W/ft² Range*
Office, enclosed	1.1	Dining area	0.9 to 2.1
Office, open	1.1	Food preparation	1.2
Conference, meeting, multipurpose	1.3	Restrooms	0.9
Classroom, lecture , training	1.4	Corridor, transition	0.5 to 1.0
Audience, seating area	0.3 to 2.6	Stairs, active	0.6
Lobby	1.1 to 3.3	Storage, active	0.8 to 0.9
Atrium, first three floors	0.6	Storage, inactive	0.3 to 0.8
Atrium, each additional floor	0.2	Electrical, mechanical	1.5
Lounge, recreation	1.2	Laboratory	1.4
Dressing/Locker/Fitting Room	0.6	Workshop	1.9

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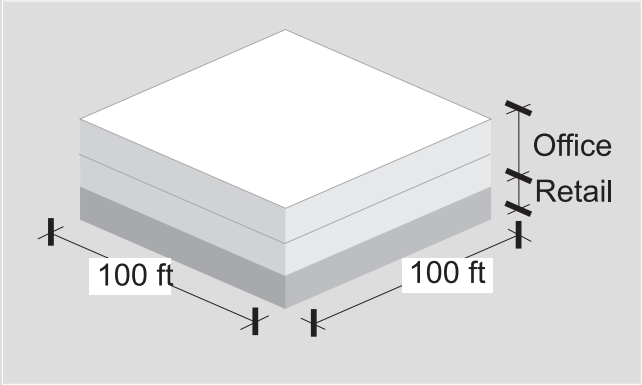
Example 9-J—Interior Lighting Power Allowance, Space-by-Space Method

Q

Use the space-by-space method to determine the interior lighting power allowance for a three-story building with retail on the ground level and office space on levels two and three. The building measures 100 ft x 100 ft and has a total area of 30,000 ft². (This example is the same as Example 9-H, except in this case, more detail is provided to enable the space-by-space calculations.)



A

Make a list of the spaces types for each building type and indicate the floor area for each space type (see the table below). For each space type, look up the lighting power density (LPD) from Table 9.6.1. The total allowance for each space type is the W/ft² density multiplied by the area of each space type. The total allowance for the 20,000 ft² of office space is 21,390 W or 1.07 W/ft². The total allowance for the 10,000 ft² of retail space is 15,295 W or 1.53 W/ft². The lighting power allowance for the whole building is 36,685 W divided by 30,000 ft² or an average of 1.22 W/ft². Compare this to the 1.17 W/ft² determined for the same building in Example 9-H.

BUILDING TYPE	SPACE TYPE	LPD (W/FT²)	AREA (FT²)	ALLOWANCE (W)
Office	Offices, enclosed	1.10	4,100	4,510
	Offices, open	1.10	12,000	13,200
	Meeting rooms	1.30	800	1,040
	Lobby	1.30	800	1,040
	Dining area	0.90	200	180
	Food preparation	1.20	100	120
	Restrooms	0.90	300	270
	Corridors	0.50	1,000	500
	Active storage	0.80	400	320
	Inactive storage	0.30	200	60
	Electrical/mechanical	1.50	100	150
	Total/Weighted Average	*1.07*	*20,000*	*21,390*
Retail	General sales area	1.70	8,000	13,600
	Offices, enclosed	1.10	200	220
	Lounge	1.20	150	180
	Restrooms	0.90	50	45
	Corridors	0.50	100	50
	Active storage	0.80	1,500	1,200
	Total/Weighted Average	*1.85*	*10,000*	*15,295*
	Whole Building Total	*1.33*	*30,000*	*36,685*

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Figure 9-D—Additional Allowance, Retail Display Lighting

Storage (Active vs. Inactive)
Two types of storage space are listed among common space types: active and inactive. Active storage space has a higher lighting power allowance because it is used more frequently. The user of terms such as "active" versus "inactive" requires judgment on the part of the designer and the authority having jurisdiction. In general, "active" means that the storage area is accessed or used for at least two hours every normal business or use day, whereas "inactive" means rare or occasional access.

Manufacturing (General Low Bay vs. General High Bay)
High bay includes spaces with a floor-to-ceiling height greater than or equal to 25 ft. Low bay includes spaces with a floor-to-ceiling height less than 25 ft.

Warehouse (Fine Material Storage vs. Medium/Bulky Material Storage)
Two building specific space categories are listed under Warehouse: fine material storage and medium/bulky material storage. Fine material storage has a larger lighting power allowance. The distinction requires judgment on the part of the designer and the authority having jurisdiction. In general, the fine material storage category should be limited to parts warehouses where items are either unpackaged or in small containers. Medium/bulky material storage, on the other hand, should be used when items are contained on palettes or in large boxes. The medium/bulky category is appropriate for all spaces where forklifts are used.

Additional Interior Lighting Power (§ 9.6.2)

Additional lighting power is allowed for decorative lighting and for retail display lighting. Additional power shall be allowed only if the specified lighting is installed, be used only for the specified luminaires, and shall not be used for any other purpose or in any other space. The term "use-it-or-lose-it" is often used to describe this type of lighting allowance. Use-it-or-lose-it means that the special allowance for additional lighting power may not be used for general lighting or for any other purpose.

In order to use these additional allowances, the lighting circuits shall be separately and automatically controlled. The most common automatic control would be a timeclock, especially for retail applications, but other automatic controls such as occupant sensors may be used to meet the control condition.

Note that prior to Standard 90.1-2007, there was an additional allowance for environments predominantly used for video display terminals (VDT), however, this additional allowance has been eliminated. The additional allowance is obsolete because of the widespread use of flat screen monitors and due to the predominance of VDTs in just about every work environment.

Decorative Lighting
Additional lighting power is permitted for decorative wall sconces, chandelier-type luminaires, and lighting that highlights art or special building features. The maximum allowance is 1.0 W/ft², and this lighting may only be used for the intended purpose. Additional lighting power is not permitted, howevervzp, if the luminaire is designed to provide general lighting. Decorative lighting installed under this exception shall have a separate, automatic control.

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Retail Display Lighting

Additional lighting power is permitted for retail displays, provided the lighting equipment is specifically designed and directed to highlight merchandise. Note that this additional display lighting shall be separately circuited, switched, and automatically controlled.

The additional allowance depends on the type of retail display area, as described below.

Sales Area Type 1 includes all retail sales floor area that does not qualify for Types 2, 3, or 4. The additional allowance for this type is 1.0 w/ft².

Sales Area Type 2 includes sale floor area for vehicles, sporting goods and small electronics. The allowance is 1.7 W/ft².

Sales Area Type 3 is floor area used for the sale of furniture, clothing, cosmetics and artwork. The allowance is 2.6 W/ft².

Sales Area Type 4 is the sales floor area used for the sale of jewelry, crystal, and china. This allowance is 4.2 W/ft².

Note that the additional allowance does not apply to the entire store, just to the sales floor area.

The authority having jurisdiction may require that the sales floor area be shown and labeled on the plans. Since display luminaires shall be controlled separately and be associated with the displays, they too may need to be identified on the plans and specifications.

Example 9-K— Lighting Systems in Retail Clothing Store

Q

A retail clothing store has five display tables that are 3 ft by 3 ft each and a separate vertical display of dresses that measures 10 ft wide and 6 ft high. What additional lighting power is permitted for these displays?

A

This is Retail Area Type 3, which specifically applies to the clothing sales floor area. This floor area includes the minor circulation areas surrounding the horizontal and vertical displays, but does not include major circulation paths that separate departments.. The additional allowance is 2.6 W/ft². Luminaries used for the display lighting should be separately identified and automatically controlled. The authority having jurisdiction may require that the display areas, the display luminaires, and the controls be identified on the plans and specifications.

A Example 9-L— Lighting Systems in Jewelry Store

Q

A jewelry store has display cases for rings, necklaces and bracelets. The store has three cases measuring 2 ft by 6 ft. What is the display allowance for these cases?

A

Jewelry is Sales Area Type 4 and the display allowance is 4.2 W/ft² times the surface area of the displays, which is 36 ft². The total allowance is 151 W. Luminaries used for the display lighting should be separately identified and automatically controlled. The authority having jurisdiction may require that the display areas and the display luminaires be identified on the plans and specifications.

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Figure 9-E—Additional Allowance, Decorative Luminaires

Figure 9-F—Additional Allowance, Decorative Luminaires

Determining the Connected Lighting Power

Once the interior lighting power allowance has been determined, it is then necessary to calculate the connected lighting power (CLP) and to show that this value is less than or equal to the allowance. Interior

Example 9-M—Wall Sconces in Office Corridor

Q

The space-by-space method is being used to determine interior lighting compliance for an office building with 1,000 ft² of corridors that provide access to private offices. Compact fluorescent wall sconces illuminate the corridors. There is no other form of illumination in the corridors. Are the corridors eligible for an additional decorative lighting power allowance? If so, is it possible to make power trade-offs between the corridor and other spaces within the office building?

A

The lighting cannot be considered decorative since it is the only source of illumination for the corridors. The lighting power allowance is 0.5 W/ft² and the power used by the wall sconces must be less than this amount or a total of 500 W for all the corridors. Since the space-by-space method is being used, trade-offs can be made between the corridors and other areas of the building.

Example 9-N—Lighting Systems in Multi-Function Rooms

Q

The space-by-space method is being used to determine interior lighting compliance for a hotel multi-function room that measures 60 ft x 120 ft. The room has two general lighting systems: a fluorescent lighting system that is used for meetings and conferences and an incandescent lighting system that consists of recessed PAR lamps in recessed cans. Controls for the two lighting system are interlocked so that only one lighting system can be turned on at a time. In addition to the two lighting systems, the room has eight chandeliers and wall sconces located around the perimeter of the room at a spacing of 10 ft. What is the lighting power allowance for the space?

A

The basic interior lighting power allowance for the room is 1.3 W/ft², which is taken from the "Conference Meeting / Multipurpose" space category (see Table 9.6.1). Since the two lighting system have controls that prevent them both from being turned on at the same time, only the system that uses the most lighting power needs to be counted in the tabulation of connected lighting power. Since the space has chandeliers and wall sconces, it qualifies for an additional 1.0 W/ft² of lighting power; however, this additional lighting power must be used only for the decorative lighting. The compliance process requires that the lighting power be separately tabulated for each general lighting system and for the decorative lighting. The power used for decorative lighting must be less than 1.0 W/ft² or a total of 7,200 W. The power used by each general lighting system must be less than 1.3 W/ft² or a total of 9,360 W. The decorative lighting cannot be traded off against lighting in other areas of the building, but the lighting for general illumination can be used for trade-offs.

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CLP is simply the sum of the input wattage of all nonexempt luminaires in the building. Luminaire wattage must be calculated in accordance with § 9.1.4. Typical input wattage for common lamp and ballast combinations is provided in the Reference section of this chapter.

Additional guidelines for rooms with multiple independent lighting systems are provided in § 9.1.4. The default tables in the Reference section may be used as an aid in calculating connected lighting power (CLP) when specific manufacturer-supplied input wattage data for lamp, ballast, and fixture combinations are not available. The building complies with the requirement for interior power if the CLP is less than or equal to the interior lighting power allowance (ILPA).

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Example 9-O—Decorative Lighting in Office Lobby

Q

An office lobby has a two-story water feature on one wall that has special lighting to provide a shimmering effect. Does this lighting qualify for the additional power allowance?

A

Yes. The additional allowance is limited to a maximum of 1.0 W/ft² and this is a use-it-or-lose-it allowance, which means that there can be no trade-offs with other lighting systems in the lobby. Furthermore, the lighting must have a separate control (see the Mandatory Provisions).

Q

An office lobby has an antique stagecoach on display, which is a symbol of the company's heritage. An incandescent track lighting system is provided to illuminate the stagecoach. Does the track lighting application qualify for additional decorative lighting power allowance?

A

Though the base allowance for the lobby is 1.3 W/ft², an additional allowance of maximum 1.0 W/ft² is available for the single purpose of lighting the stagecoach area.

Example 9-P—Comparison of Building Area and Space-by-Space ILPAs, Retail Clothing Store

Q

Which method—building area or space-by-space—provides a more generous interior lighting power allowance for a small retail store with many feature displays? The ceiling height is 16 ft, the gross lighted area is 3,000 ft², the sales area is 2,400 ft² (of which 1900 ft² is sales departments and 500 ft² is major circulation), the dressing rooms are 300 ft² with a ceiling height of 10 ft, and the storage area is 300 ft².

A

The space will qualify for additional lighting power for display if the space-by-space method is used to determine the lighting power allowance. The additional lighting power is not permitted if the building area method is used to determine the interior lighting power allowance. The building area method (Table 9.5.1) allows 1.5 W/ft² or 4,500 total W.

With the space-by-space method, the allowance has to be calculated separately for the sales area, the dressing rooms, and the storage area. For the 2,400 ft² sales area, Table 9.6.1 allows 1.7 W/ft², resulting in a total of 4,080 W. The dressing rooms are allowed 0.6 W/ft² or 180 total W. The storage area is considered active storage and is permitted 0.8 W/ft² or 240 total W. The total allowed lighting power with the space-by-space method is therefore 4,080 + 180 + 240 or 4,500 W. This happens to be equal to the allowance permitted using the building area method. However, with the space-by-space method, the store would be eligible for additional lighting power for display purposes.

The maximum additional power allowed is 2.6 W/ft² (Retail Area 3) for the sales floor area, including minor circulations paths but excluding major circulation paths between departments. The allowance is calculated at 2.6 W/ft² times 1900 ft² (sales floor area), resulting in 4940 W. Furthermore, this additional power shall be allowed only if the specified lighting is installed, shall be used only for the specified luminaires, shall not be used for any other purpose or in any other space. Display lighting must have an independent control (see the Mandatory Provisions).

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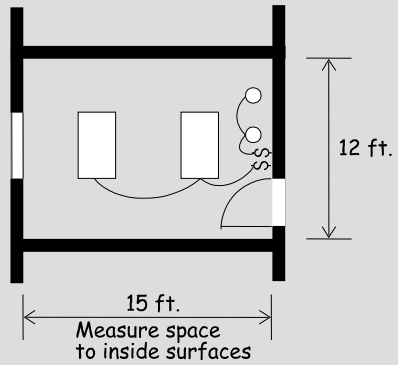
Example 9-Q—Interior Lighting Power Allowance, Private Office

Q

A 12 ft by 15 ft private office with a 9 ft ceiling has two recessed three-lamp parabolic luminaires for general and task lighting, as well as two recessed downlights. Each parabolic fixture has a three-lamp electronic ballast and F32T8 lamps. A wallbox occupancy sensor controls the parabolic fixtures, and a manual wallbox dimmer controls the downlights. Does this space comply with the interior lighting requirements?



A

Using the space-by-space method, the ILPA for this space is 1.1 W/ft². A total of 198 W is permitted (1.1 x 12 x 15). The two 50 W labeled downlights, while the input wattage of the parabolic fixtures is 89 W apiece. The connected lighting power, therefore, is 278 W, which is greater than the 198 W that are allowed. The building may still comply with the Standard, provided the 80 W difference is made up somewhere else in the building.

The space complies with the control requirements, however. The occupant sensor meets the space control requirement that applies to all rooms surrounded by ceiling-height partitions. The dimmer for the downlights adds additional and useful control. Since two three-lamp ballasts are used to control the parabolic luminaires, the requirement for tandem wiring does not apply.

Example 9-R—Interior Lighting Power Allowance, Multi-Use Facility

Q

The gross lighted area of a multi-use facility consists of 100,000 ft² of mall concourse, 250,000 ft² of retail space that abuts the mall concourse, 500,000 ft² of office space in a tower above the retail space, and 50,000 ft² of parking garage. What is the ILPA?

A

The gross lighted area of the project is 900,000 ft². Using the building area method, the interior lighting power allowance for the project is 1,040 kW (1.16 W/ft²) as derived below.

USAGE CATEGORY	AREA (FT²)	W/FT²	ALLOWANCE
Office	500,000	1.00	500,000
Mall concourse (retail)	100,000	1.50	150,000
Retail	250,000	1.50	375,000
Garage	50,000	0.30	15,000
Totals	*900,000*		*1,040,000*

Note, however, that each of these uses must comply separately unless the lighting systems are all included in the same permit.

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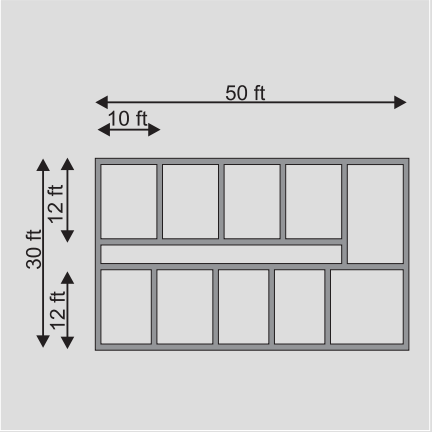
Example 9-S—Interior Lighting Power Allowance, Office Building



Q

A building consists of 10 similar private offices ranging from 10 ft by 12 ft to 10 ft by 14 ft in size and totaling 1,350 ft² (average size 135 ft²). In addition, the building has 150 ft² of corridors. The total floor area of the building is 1,500 ft². What is the interior lighting power allowance for the building?

A

Using the building area method, the interior lighting power allowance is 1,500 ft² x 1.0 W/ft² = 1,500 W.
Using the space-by-space method, the allowance for the enclosed offices is 1,350 ft² x 1.1 W/ft² = 1,485 W. The allowance for the corridors is 150 ft² x 0.5 W/ft² = 75 W. The total allowed interior lighting power (without additional power allowances) is 1,560 W.

Example 9-T—Interior Lighting Power Allowance, Multi-Use Hotel Ballroom

Q

An 8,000-ft² hotel ballroom with a 16 ft ceiling serves also as a meeting/exhibition room. A fluorescent lighting system (8,500 W) is used for the meeting and exhibition functions. A separate lighting system uses 10,000 W and consists of incandescent downlights. In addition, the space has wall sconces and chandeliers that draw 6,000 W. The total connected lighting power for all systems is 8,500 + 10,000 + 6,000 or 24,500 W. What is the interior lighting power allowance for this room? Does the lighting system described comply with the Standard?

A

Using the space-by-space method, the allowed interior lighting power density for this room is 1.3 W/ft². This is read from Table 9.6.1 as the "Conference Meeting/Multi-purpose" space type. Therefore, the base allowance is 8,000 ft² x 1.3 W/ft² = 10,400 W. The space is eligible for an additional 1.0 W/ft² or 8,000 W for decorative lighting.
The fluorescent lighting system and the incandescent lighting systems each have a power draw that is less than the allowance of 10,400 W. They could both be installed, but only if they are controlled to prevent simultaneous operation. The use-it-or-lose-it allowance for decorative lighting is 8,000 W and the installed lighting is 6,000 W so the wall sconces and chandeliers comply, provided their lighting is circuited and controlled separately from the other systems.

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Installed Interior Lighting Power (§ 9.1.3)

The installed or connected lighting power – which is compared to the allowed lighting power – must include not just the lamp, but also the power used by the ballast, the control (when applicable), transformers, and any other power draws associated with the lighting system.

Most of the time, it is only necessary to include the power used for the lamp and ballast, as the power required for controls is either zero or so small that it can be ignored. Some types of lighting applications are exempt and, consequently, do not have to be considered. Exempt lighting applications are listed in the exceptions to § 9.2.2.3 of the Standard.

Some lighting applications have multiple systems that are not intended for simultaneous operation. For example, a multi-function room in a hotel might have one lighting system with incandescent downlights appropriate for ballroom activities and another lighting system to provide office-level illumination suitable for meetings and conferences. If controls are provided so that it is not possible to turn on both lighting systems at the same time, then it is only necessary to look at the lighting system with the greatest power when determining compliance with the Standard.

Luminaire Wattage (§ 9.1.4)

With many types of luminaires, designers may be uncertain about the watts to use in compliance calculations. This is particularly true for luminaires that can accept different sizes and for track lighting where additional luminaires can easily be added. This section of the Standard explains how the wattage is determined for these special cases.

Example 9-U—Interior Lighting Power Allowance, Tenant Improvement

Q

A tenant takes over a floor in an office building summarized in the table below. What is the interior lighting power allowance (ILPA) of the project?

A

Since this is a tenant improvement and does not represent an entire building or a complete occupancy within a building, only the space-by-space method can be used to determine the ILPA, unless separately metered and permitted. The calculation is summarized in the following table. In this case, there are a few judgment calls: the coffee/copy room is treated as a dining area at 0.9 W/ft², telephone equipment is treated as Electrical/Mechanical at 1.9 W/ft², and the computer room is treated as open plan office at 1.1 W/ft². Depending on the circumstances, the coffee/copy room could be considered office or active storage. The computer room might also be considered active storage. The total allowance is 13,412 W or 1.09 W/ft².

SPACE	Area (ft²)	W/ft²	W
Office, enclosed	3,750	1.1	4,125
Office, open plan	5,570	1.1	6,127
Conference	670	1.3	871
Corridors	640	0.5	320
Employee lounge	220	1.2	264
Lobby	450	1.3	585
Elevator lobby	350	1.3	455
Computer room	250	1.1	275
Coffee/Copy room	300	0.9	270
Telephone equipment	80	1.5	120
otals	12,280		13,412

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Incandescent and Tungsten-Halogen Luminaires without Permanently Installed Ballasts
This type of luminaire can accept lamps of many different sizes. When determining compliance, assume the maximum labeled wattage of the luminaire. This means that a luminaire rated for 150 W is calculated at 150 W for lighting power allowance compliance purposes. This applies regardless of whether the lamp is 75 W incandescent or 13 W screw-in compact fluorescent, since the luminaire does not contain a permanently installed ballast. To achieve credit for compact fluorescent lamps, the fixture must have a permanently installed ballast.

Luminaires with Permanently Installed Ballasts
Luminaires with permanently installed or remote ballasts shall use the input watts of the lamp/ballast combination shown on the plans and specifications for the building. This information can be taken from manufacturer's literature or from an independent testing laboratory. In addition, the Reference section of this chapter has data that can be used in lighting compliance calculations. Data in the Reference section are provided for common fluorescent, compact fluorescent, and high-intensity discharge (HID) sources.

Line-Voltage Track Lighting
Track lighting is a very common lighting technique for display lighting in retail stores and galleries. It consists of a line-voltage, plug-in busway that allows the addition or relocation of luminaires without having to change the wiring system. It's very easy to add fixtures to the track after the final occupancy permit has been issued. When accounting for track lighting that operates at line voltage, the designer must assume at least 30 W per lineal foot of track (98 W/lin m), the wattage limit of the system's circuit breaker, or the wattage limit of other permanent current limiting devices on the system. If the plans and specifications show more than 30 W/ft (98 W/lin m), the greater installed power must be used for compliance purposes.

Low-Voltage Track Lighting
Some track lighting systems use a transformer to energize the busway at 12 or 24 volts. Examples include decorative fixtures that have exposed conductors. These systems allow fixtures to be easily added, removed, or relocated without having to modify the wiring system. When these systems are used for interior lighting, the wattage used for compliance calculations is the maximum wattage of the transformer that supplies power to the system.

Other
For all other types of luminaires not specifically addressed above, the wattage shall be the specified wattage of the lighting equipment, taken from the plans and specifications.

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Reference

The first-time or occasional user of the Standard may be unfamiliar with some of the terms used in § 9. Most of these terms are defined in § 3 of the Standard but may need some further clarification. This Reference section is included to provide additional helpful information regarding terminology and concepts that are used when describing lighting systems. The following topics are covered in this Reference section: Floor Area, Ballasts, Efficacy, Lighting Power Data and Lighting Controls. In addition, a conversion table is included to assist with converting from I-P to SI units.

Floor Area

Gross Lighted Area

The gross lighted area is used in the building area method of determining interior lighting power allowance. The gross lighted area of the building is the gross floor area of lighted spaces in the building. It includes basements, mezzanines and intermediate-floor tiers, and penthouses, provided these spaces have a headroom height of 7.5 ft (2.3 m) or greater. The gross lighted area is measured from the exterior faces of exterior walls or from the centerline of walls separating buildings. The gross lighted area excludes covered walkways, open roofed-over areas, porches and similar spaces, pipe trenches, exterior terraces or steps, chimneys, roof overhangs, and similar features.

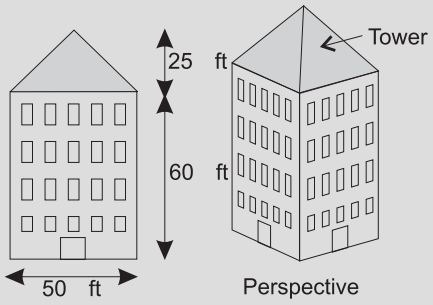
Gross Interior Lighted Area

The gross interior lighted area is used for the space-by-space method of determining the interior lighting power allowance. The sum of all the gross interior lighted areas is equal to the gross lighted area. Each interior lighted area is measured to the outside surface of exterior walls and to the centerline of interior partitions. It should

Example 9-V—Exterior Building Lighting Power Allowance, Building Façade

Q

A building consists of a four-sided pyramid atop a four-sided tower with no cornices or soffits. What is the appropriate method for determining the building façade lighting power allowance?



A

If all sides of the building as well as the pyramid are intended to be illuminated, the entire surface area of the building may be used to determine the power allowance. Each vertical surface is 60 ft by 50 ft = 3000 ft² for a total area of 12,000 ft². The area of each triangular face of the pyramid is determined by multiplying the base (50 ft) times height (25 ft) and dividing by two. This yields a total area of 2,500 ft² for the pyramid. The overall façade area, therefore, is 12,000 + 2,500 = 14,500 ft². The unit power allowance is 0.20 W/ft² of surface area to be illuminated; therefore, the maximum power allowance for illuminating the façade of the building is 2,500 W. (Note that the unit power allowance only applies to the surface area intended to be illuminated, which may not always be the entire surface area of the building.)

Example 9-W—Exterior Building Lighting Power Allowance, Building Cornice

Q

A cornice that is designed to be illuminated protrudes from the façade of a building. Does it receive any special exterior building lighting power allowance?

A

It receives a power allowance based on its vertical projected area; thus, it does not matter how far it protrudes. Ordinarily, the cornice top is not intended to be illuminated, so its area is ignored.

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include mezzanines or balconies that extend into the space.

Ballasts

Lamp ballasts are used with all discharge lamps, including fluorescent, mercury vapor, metal halide, and high and low pressure sodium. Unlike incandescent lamps, which use electric current to heat a tungsten filament until it produces visible light, discharge lamps pass an electric arc across electrodes sealed in a gas-filled tube, ionizing the gas and releasing electrons. For proper lamp operation, the electric arc must be maintained at a very specific voltage and current. The ballast serves this function. In some cases, the ballast also provides the voltage that starts (or strikes) the arc.

Electronic high-frequency ballasts represent relatively recent advances in technology that have created tremendous opportunities for improved lamp performance, increased energy efficiency, and enhanced design flexibility. Electronic ballasts take incoming 60 Hz power and convert it to high-frequency AC. Electronic ballasts are more efficient than magnetic ballasts in converting input power into optimal lamp power. For example, operating fluorescent lamps at high frequency increases lamp/ballast system efficacy by 15% to 20%. Electronic ballasts also offer the following additional advantages over magnetic ballasts:

- With high-intensity discharge (HID) lamps, electronic ballasts offer relatively precise management of the lamp's arc tube wattage, usually resulting in longer lamp life and more consistent color.
- Electronic ballasts are much quieter than magnetic ballasts.
- Electronic ballasts reduce fluorescent lamp flicker to a level that is essentially imperceptible.
- Electronic ballasts are readily available to operate three or four lamps, reducing tandem wiring requirements as well as labor costs for installation and field wiring.
- An increasing number of sophisticated lighting control components are now available for electronic ballasts, including dimming and light-level switching capabilities. This has enhanced the availability and flexibility of lighting control strategies for designers.

Efficacy

Efficacy is the ratio of light output to watts input; it is commonly used to describe the lighting energy efficiency of a lamp/ballast system. There are essentially three ways to improve the efficacy of a lamp/ballast system:

- Reduce ballast losses.
- Reduce losses created by constantly heating lamp electrodes.
- Operate lamps at high frequency.

All three of these methods involve the ballast component of the system. Newer ballast products exploit one or more of these techniques to increase lamp/ballast system efficacy. Ballast losses can be reduced by using a single ballast to drive three or four lamps, instead of one or two. Ballast losses may also be reduced by using copper (as opposed to aluminum) windings and high-grade magnetic components in electromagnetic ballasts and by using quality circuit design in electronic high-frequency ballasts. Some electromagnetic ballasts are able to shut off the voltage to fluorescent lamp electrodes once the lamp has started, thus increasing efficacy. Electronic ballasts, which operate fluorescent lamps at high frequency, offer the greatest increase in system efficacy.

Lighting Power Data

Calculating the connected lighting power (CLP) to determine compliance with both the interior and exterior lighting power requirements means determining the input wattage used by all light fixtures. Except for incandescent sources, fixture input wattage is not the same thing as lamp wattage. Input wattage for all discharge sources (which are most common in nonresidential buildings) is determined by the interaction between lamps, ballast, and fixture construction. A high-efficacy system uses less input wattage to produce the same amount of light as a lower efficacy system. However, the two components of efficacy—input wattage and light output—are both affected by the ambient temperature in which they operate.

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The light output and input wattage ratings listed in lamp manufacturer catalogs are determined under very specific laboratory conditions in which the lamp is operated by a "reference ballast" in free air at a temperature of 77°F (25°C). However, lamps behave quite differently when they are inside a light fixture. Light fixtures are hot places, particularly if they are enclosed, located in a plenum, or otherwise poorly ventilated. Temperatures that exceed 77°F (25°C) reduce both the rated light output of the lamp and fixture input wattage.

It is important that input wattage be determined, if possible, by using data supplied by the lighting fixture or ballast manufacturer. The default wattage tables in the following pages are included in this Manual to supply a source of information when manufacturer data are missing or unknown. While manufacturer data are preferred when determining connected lighting power, the data given here will suffice, provided the values are used prudently. Users are encouraged to review the following notes on interpreting the table values:

- ANSI values listed for fluorescent systems assume open-air operation of lamps at 77°F (25°C). These data should be used for open, suspended luminaires and heat extract-type recessed troffers.
- Input wattage values for enclosed lamps are generally less than they are under ANSI conditions. It is important to note that while input wattage is reduced in enclosed luminaires, so is light output. Partial listings for enclosed lamps are shown when available (fluorescent systems only). These values are for static (not heat-extract) lensed luminaires recessed into acoustical tile ceilings.
- ANSI input wattage values listed for electronically ballasted rapid-start and instant-start systems represent averages taken from manufacturers' catalogs. Input wattage values for these products vary considerably due to the availability of different ballast factors from manufacturers. High ballast-factor ballasts require more input watts than low ballast-factor ballasts, but they produce more light output from the same lamps. The reverse is true for low-wattage reduced output electronic ballasts.

Table 9-D—Typical Lighting Power for Magnetically Ballasted Fluorescent Lamp/Ballast Systems (W)

Lamp/Ballast Combination	4 Lamps, 2 Ballasts Open	3 Lamps, 2 Ballasts Open	3 Lamps, Tandem-Wired Ballasts Open	2 Lamps, 1 Ballast Open
Standard Magnetic Energy Saving Ballasts				
31-W FB31T8		105	104	69
32-W F32T8	140	106	105	70
34-W F40T12/ES	144	112	108	72
40-W F40T12	176	134	129	88
40-W FB40T12		134	129	86
40-W F40T5 Twin Tube		130		86
60-W F96T12/ES Slimline				123
75-W F96T12 Slimline				158
95-W F96T12/High Output/ES				208
110-W F96T12/High Output				237

Notes: Data listed are for standard energy-efficient magnetic ballasts. Values listed for three-lamp systems with two magnetic ballasts have one single-lamp ballast and one-double lamp ballast.

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Table 9-E—Typical Lighting Power, Electronic Ballasted Fluorescent Lamp/Ballast Systems (W)

Lamp/Ballast Combination	4 Lamps, 1 Ballast	3 Lamps, 1 Ballast	2 Lamps, 1 Ballast	1 Lamp, 1 Ballast
265 mA T-8 Lamps				
17-W F17T8	63	53	33	22
25-W F25T8	89	68	48	27
31-W FB31T8		92	62	39
32-W F32T8	114	93	62	32
40-W F40T8		112	79	46
59-W F96T8			110	
86-W F96T8HO			160	88
T-12 Lamps				
34-W F40T12/ES	121	90	62	31
60-W F96T12/ES Slimline			107	70
75-W F96T12 Slimline			132	85
110-W F96T12/HO/ES			170	
95-W F96T12/HO			205	119
Twin Tube Long Compact Fluorescent Lamps				
36-W F36TT			70	37
40-W F40TT		103	72	41
50-W F50TT			106	54
55-W F55TT			112	58
T-5 normal and HO linear lamps				
14-W F14T5			34 (PS)	18 (PS)
21-W F21T5			50 (PS)	27 (PS)
28-W F28T5			60 (PS)	30 (PS)
24-W F24T5HO			52 (PS)	27 (PS)
39-W F39T5HO			85 (PS)	43 (PS)
54W F54T5HO			117 (PS)	62 (PS)

Notes: Data listed represent averages of products available from established manufacturers of electronic ballasts. Actual input wattage values for these systems may be tuned by using specific products, and will differ from these values.

Systems shown have minimum 0.85 ballast factor

T5 linear lamps use programmed start (PS) ballasts with ballast factor approximately 1.0.

Lighting Controls

High-efficiency lighting components, such as T-8 fluorescent lamps and electronic high-frequency ballasts, make a significant impact on lighting energy and its associated costs by reducing the kW required to light buildings. Lighting controls, on the other hand, affect lighting energy by directly reducing lighting's time of use. Some lighting control techniques, such as using photocell controls in building spaces that incorporate daylighting, not only reduce lighting time of use but also decrease lighting power and may even reduce the average cost of electricity by eliminating some lighting kW during peak demand periods.

Stepped Lighting Control Systems

There are two ways to control lighting systems: by switching and by dimming. When switching systems are used with entire circuits of lights, as opposed to individual light fixtures, the control protocol is usually described in terms of steps, with each numerical "step" referring to a percentage of full lighting power.

Stepped lighting control systems may be designed to switch either individual fixtures, individual ballasts within fixtures, or both. The control scheme is determined by the design of the electrical circuiting. Typically, a control device in the form of a photocell, occupancy sensor, or time switch sends a signal to a signal processor. The processor then switches individual relays or contactors that control lighting circuits.

The major advantage of stepped lighting control systems is that they are a relatively inexpensive approach to automatic lighting control of large individual spaces.

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Table 9-F—Electronically Ballasted High or Low-Wattage Fluorescent Lamp/Ballast Systems

Lamp/Ballast Combination	4 LAMPS, 1 BALLAST		3 LAMPS, 1 BALLAST		2 LAMPS, 1 BALLAST		1 LAMP, 1 BALLAST	
	Watts	Ballast Factor	Watts	Ballast Factor	Watts	Ballast Factor	Watts	Ballast Factor
25W F25T8	76	RO	59	RO	41	RO	24	RO
			74	HO	51	HO	29	HO
32W F32T8	98	RO	76	RO	51	RO	29	RO
	152	HO	114	HO	78	HO	38	HO
					86	NO		
36W F36T8 Twin Tube					85	NO	46	NO
40W F40T5 Twin Tube							45	NO

Notes: *RO=Reduced Output and Ballast Factor (~0.77)*
HO=High Output and Ballast Factor (~1.2)
NO=Normal Output and Ballast Factor (~0.88)

Their primary drawback, however, is that they can be very distracting to occupants in a space. The change in the space's appearance is pronounced and abrupt, and often there is an audible snap as the relays switch. Generally, this problem is limited to cases when stepped switching is combined with photosensors as part of a daylighting control system.

Stepped controls also limit the flexibility of the design, in terms of offering only preset lighting levels. By contrast, continuous dimming systems are able to tune the light levels in response to a preset design criterion.

Continuous Dimming Control Systems

Continuous dimming control systems are designed to adjust electric lighting in a space to maintain a designed lighting level. Typically, these systems include a photocell to monitor lighting levels, a signal processor, and electronic dimming ballasts, which alter the current to the lamps in response to the signal coming from the processor. Continuous dimming is a fluid, dynamic means of light control: ambient light can be constantly monitored and lamp output adjusted accordingly.

Properly designed and maintained continuous dimming systems offer several advantages over stepped controls:

- There are no distracting and abrupt changes in lighting levels to distract the occupants of the space.
- Appropriate lighting levels, with respect to visual task requirements, can be maintained in the space at all times.
- There is a much greater range of electric light level available. Some ballasts can dim lamps down to 1% of full output.

The primary disadvantage of continuous dimming is its cost. Each light fixture must have a dimming ballast, which can add a significant cost premium.

Automatic Control Strategies

Several different approaches can be used to control electric lighting. The control hardware and design practices used with the strategies listed here are discussed in more detail below.

- Scheduling Control: Use a time-scheduling device to control lighting systems according to predetermined schedules.
- Occupancy Sensing: Control lights in response to the presence or absence of people in the space.
- Daylighting: Switch or dim electric lights in response to the presence or absence of daylight illumination in the space.
- Lumen Maintenance: Gradually adjust electric light levels over time to correspond with the depreciation of light output from aging lamps.

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Table 9-H—Power for High-Intensity Discharge Lamps

	Lamp Watts	Fixture Input Watts
Mercury Vapor Lamps	75	88
	100	119
	175	197
	250	285
	400	450
	1,000	1,080
Metal Halide Lamps—Magnetic and Electronic Ballasts	35/39	44 Electronic
	35/39	48
	50	58 Electronic
	50	68
	70	86 Electronic
	70	92
	100	110 Electronic
	100	122
	150	168 Electronic
	150	186
	175	205
	250	295
	320	345 Linear Reactor
	360	388 Linear Reactor
	400	426 Linear Reactor
	400	461
	450	502
	750	820
	1,000	1,080
High Pressure Sodium Lamps	35	44
	50	61
	70	86
	100	122
	150	173
	200	240
	250	302
	400	469
	1,000	1,090

Notes: Source: California Energy Commission Title 24 2005 Nonresidential ACM Manual Appendix NB.

Table 9-G—Power for Compact Fluorescent Lamps

Lamp Type	Ballast Type	Input Watts
5-W twin-tube	Electro-magnetic	9
7-W twin-tube	Electro-magnetic	11
9-W twin or quad-tube	Electro-magnetic	13
13-W twin or quad-tube	Electro-magnetic	17
18-W quad-tube	Electro-magnetic	25
26-W quad-tube	Electro-magnetic	37
28-W quad-tube	Electro-magnetic	34
9-W twin or quad-tube (4-pin base)	Electronic	10
13-W twin, triple or quad-tube (4-pin base)	Electronic	14
10-W quad-tube (4-pin base)	Electro-magnetic	16
18-W triple or quad-tube	Electronic	21
26-W triple or quad-tube	Electronic	28
32-W triple-tube	Electronic	35
42-W triple or quad-tube	Electronic	46
57-W triple or quad-tube	Electronic	62
70-W triple or quad-tube	Electronic	75

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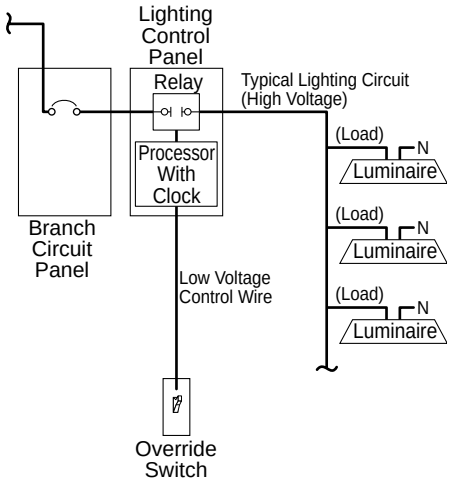

Figure 9-G—Scheduling Control

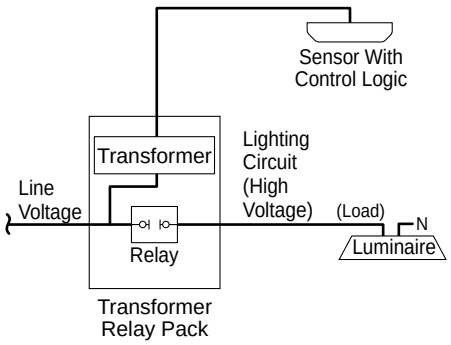

Figure 9-H—Occupancy-Sensing Control

Scheduling Controls

Programmable timing, also known as automatic time scheduling, is the oldest form of automatic lighting control. Time scheduling manages the on and off times of a building's lighting systems.

Scheduling systems function by turning off all or some of the lights when a building space is unoccupied. In the most basic time-scheduling scheme, a time switch switches lighting circuits on or off based on programmable schedules. For example, exterior lighting is usually switched on to correspond to sundown and is switched off again at daybreak. By contrast, time scheduling of interior lighting systems is based, for the most part, on occupancy schedules. In some cases, time switches are used to energize additional lighting control systems, such as daylighting controls, which are held off during unoccupied periods.

Time-scheduling systems employ the following components:

- A *central* processor is usually capable of controlling several output channels, each of which may be assigned to one or more lighting circuits.
- Relays are series-wired to lighting control zones and are controlled by the central processor.
- *Overrides* are required to accommodate individuals who use the space during scheduled off hours. Individuals can activate manual switches or use telephone overrides to regain temporary control of the lights in a given space.

In most cases, Class 2 (low voltage) wiring links all the components in the system, and the system uses a flashing warning system to let individuals know that the lights are going off. This allows occupants either to vacate the space or activate an override to keep the lights on.

The crucial component in any time-scheduling system is the programmable central processor, which is essentially a multiple-circuit controller. The central processor can be programmed by building maintenance personnel to schedule on and off loads on each of its output channels. If desired, several different on-off sequences may be programmed on each channel.

A central processor typically consists of the following components.

- A programmable microprocessor with electronic clock is capable of separately scheduling weekday, weekend, and holiday operation. Astronomical timekeeping ability means that the processor is able to make seasonal and daylight savings adjustments.[9] Typically, the processor has a built-in battery backup so that the programmed schedule remains in memory during power outages. The processor is usually able to "sweep" at regular intervals during its off hours. The processor remembers when overrides have been employed to keep lights on in any particular area; the processor will then repeat the operation to turn off the lights.
- Switch inputs allow occupants to override the shutoff function of the processor. Usually the switches and wiring to the controller are low voltage. Inputs may also be wired to photocells or occupancy sensors for additional flexibility.
- Output channels are required for each lighting control zone. Sophisticated designs sometimes provide two or more outputs for each control zone. This allows for stepped control of the zone. In some systems, output channels can be designed to provide a variable signal, allowing for dimming applications.

Generally, time scheduling is the most effective way to save lighting energy when occupancy patterns are relatively regular or when lighting operating hours are easy to predict. Exterior lighting controlled with an astronomical time switch is the best example of this type of application.

Occupancy Sensors

Occupancy sensors are automatic scheduling devices that detect motion and turn lights on and off accordingly. Most devices can be calibrated for sensitivity and for the length-of-time delay between the last detected occupancy and extinguishing of the lights. The most

[9]. The power of the microchip now allows for one-time programming of all 365 days in the year.

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energy-efficient occupancy sensors, known as "manual-on, automatic-off," require that the user manually switch on the lights when entering a controlled zone (the "lights off" function is still automatic).

Occupancy sensor systems typically consist of a motion detector, a control unit, and a relay. Usually, two or more of the components are integrated into one package. Most systems also require a power supply in the form of a transformer, which steps down the building voltage to 24V. The detector collects information, then sends it to the controller, where it is processed. Output from the controller activates the relay, which in turn switches the light circuit.

There are two major types of occupancy controls.

- *Wallbox* units are designed to fit into a standard wall switch box and operate on the building voltage (i.e., a separate power supply is not required). They are excellent, inexpensive replacements for standard wall switches. Their main limitation is their relatively short range. Consequently, they tend to be used in small offices and meeting rooms.
- Wall and Ceiling units typically contain an integrated sensor/controller unit wired (Class 2) to a switch pack containing the relay and power supply. They are far more popular than wallbox units and have very few application limitations.

Occupancy-sensing lighting controls represent a refinement of the technology developed in the early 1970s to detect intruders for residential and commercial security applications. With lighting control, two different means of detecting occupancy are used:

- *Passive Infrared (PIR) sensors* perceive and respond to the heat patterns of motion. This same technology is used in most residential and commercial security systems. The chief advantage of PIR sensors is that they are relatively inexpensive and reliable. They very rarely "false trigger" (that is, respond to non-occupant motion in a space). The major limitation of PIR sensors is that they are strictly line-of-sight devices, unable to see around corners or partitions.
- Ultrasound (US) detectors radiate ultrasonic waves into a space, then read the frequency of the reflected waves. Motion causes a slight shift in frequency, which the detector interprets as occupancy. They are more sensitive than PIR sensors, which is both an advantage and a disadvantage. They are often used very effectively in partitioned spaces but are also more prone to false triggering due to their sensitivity to air movement. Proper design and installation minimizes this potential problem.

Many occupancy sensor manufacturers also offer products that integrate both PIR and US technology into one package. Typically, these are designed to avoid false triggering by holding the lights off unless both detectors sense motion in the space.

Although is difficult to generalize about the amount of lighting savings attributable to the use of occupancy sensors, they are consistently cost-effective for many lighting applications. All applications are different, and actual savings depend on occupancy patterns, lighting schedules, employee habits, and many other factors. Occupancy sensors are most effective in building spaces where occupancy is sporadic or unpredictable and in spaces, such as storage areas, where the lights are likely to be left on inadvertently. Typical savings range from 10% in large open offices to 60% in some warehouse applications. In many cases, occupancy sensors pay for themselves in less than a year.

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Compliance Forms

Instructions

Compliance forms are provided in the User's Manual to assist in understanding and documenting compliance with the lighting requirements. Copies of the compliance forms are provided both in printed and electronic form. Modifiable electronic version are included on the CD that accompanied this Manual, as well as available for download from the ASHRAE website.

The lighting forms are organized on three pages and in eight sections, beginning with header information and mandatory measures and concluding with exterior lighting requirements.

Header Information

Project Name: Enter the name of the project. This should agree with the name that is used on the plans and specifications or the common name used to refer to the project.

Project Address: Enter the street address of the project, for instance "142 Minna Street."

Date: Enter the date when the compliance documentation was completed.

Designer of Record/Telephone: Enter the name and the telephone number of the designer of record for the project. This will generally be an architecture firm.

Contact Person/Telephone: Enter the name and telephone number of the person who should be contacted if there are questions about the compliance documentation.

City: The name of the city where the project is located.

Mandatory Provisions Checklist

This section of the compliance form summarizes the Mandatory Provisions for the design of the lighting system. The mandatory measures are organized on this form in the same order as they are in the Standard. Check the box to indicate that the mandatory requirement applies to the building and that the building complies with the requirement. If the requirement is not applicable, then leave the box unchecked.

Interior Lighting Power Allowance (Building Area Method)

Complete this section of the form if the building area method is used to determine the interior lighting power allowance. Complete a row in this table for each building type in your building. For instance, if you have a three-story building with the first floor retail and the upper two floors office, you would enter two building types.

Building Type: Select a building type from the first column of Table 9.5.1 and write the name in this column.

Lighting Power Density (W/ft²): Select the lighting power density from Table 9.5.1 that corresponds to the building type entered in the first column.

Building Area (ft²): Enter the building floor area for this building type.

Lighting Power Allowance (W): Multiply the Lighting Power Density times the Building Area to get the Lighting Power Allowance and enter the product in this box. Once the Lighting Power Allowance is calculated for each Building Type, then sum the values and enter in the box labeled Total.

Interior Lighting Power Allowance (Space-by-Space Method)

Complete this section of the form if the space-by-space method is used to determine the interior lighting power allowance. Complete a row in this table for each unique space in your building.

Building Type: Select a building type from the first column of Table 9.6.1 and write the name in this column.

Common/Specific Space Type: Select the common space type from the columns in Table 9.6.1 or choose one of the Specific Space Types from the right side of Table 9.6.1.

Lighting Power Density (W/ft²): Select the lighting power density from Table 9.6.1 that corresponds to the building type and space types entered in the first two columns.

Space Area (ft²): Enter the floor area of the space.

Lighting Power Allowance (W): Multiply the Lighting Power Density times the Space Area to get the Lighting Power Allowance and enter the product in this box. Once the Lighting Power Allowance is calculated for each Space Type, then sum the values and enter in the box labeled Total.

Interior Connected Lighting Power

Use this portion of the form to calculate the connected lighting power for the interior of the building. Fill out a row in this table for each type of luminaire you have. This list will generally match the lighting fixture schedule found on the electrical drawings.

ID: Enter a code number or ID that is consistent with the lighting schedule on the plans and specifications. This identification should enable a plan checker to identify the location of luminaires of this type on the plans.

Luminaire Description: Provide a description of luminaire including information such as the number of lamps, watts per lamp, type of ballast, and type of fixture.

Type: Select one column to indicate the type of lighting source used for this luminaire. The choices are incandescent, fluorescent, HID, line-voltage track, low-voltage track, and other.

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Number of Luminaires: Enter the number of luminaires of this type that are located in the building.

Watts/Luminaire: Enter the total W of power per luminaire. Be sure to include consideration of the ballast and any other factors that affect input power.

Total Watts: Calculate the total watts of power for this luminaire by multiplying the power per luminaire times the number of luminaires.

Total: Calculate the total installed W for the building by adding the total watts for each luminaire type. In order for the building to comply, this value must be less than the Total Lighting Power Allowance calculated with either the space-by-space method or the building area method.

Additional Interior Lighting Power Allowance

Use this section of the form to identify additional lighting power that is permitted by § 9.6.2. This section of the Standard allows additional lighting power for decorative purposes such as wall sconces or chandeliers, for lighting installed to meet the requirements of video display terminals, and for display lighting in sales areas. These special lighting power allowances may only be used for their intended purpose. If the installed power is smaller than the allowance, the surplus power may not be allocated to another portion of the building. This type of allowance is often called a "use-it-or-lose-it" allowance.

Space ID: Enter an identification code for the space where the special allowance applies. This code should be consistent with the numbering scheme on the plans. Typically, the room number from the plans will be entered in this space.

Space Name: Enter a descriptive name for the space. This should be consistent with the name used on the room schedule on the plans. The Space ID, however, is the principal link back to the plans from the compliance form.

Type: Enter the type of special allowance that applies. Choose just one. The choices are Decorative and Display Lighting. See § 9.6.2 of the Standard for more details on these allowances.

Area (ft²): Enter the applicable area for the special allowance.

Unit Allowance (W/ft²): This allowance is fixed. Enter 1.0 W/ft² for the Decorative allowance or either 1.0, 1.7, 2.6 or 4.2 W/ft² for the Display Lighting allowance. See § 9.6.2 of the Standard for more details.

Allowance (W): Calculate the Allowance by multiplying the Area times the Unit Allowance. Enter the product in this box.

Luminaire IDs: Enter the identification numbers of the luminaires used for the intended purpose. If the allowance is for decorative lighting, the ID should reference a chandelier or wall sconce that satisfies the decorative lighting requirement. The IDs entered in this column should be consistent with those used in the lighting schedule on the plans and in the next section of the lighting compliance form labeled Additional Interior Connected Lighting Power.

Installed Power (W): Enter the lighting power actually installed in the room for the intended use. If the allowance is for decorative or display lighting, this value should represent the lighting power for the qualifying fixtures. This value must be lower than the allowance for each type of allowance and within each room. In other words, the value in the last column must be less than the value in the next to last column in every row of the table.

Additional Interior Connected Lighting Power

This table provides additional documentation on the lighting equipment installed for the additional lighting allowance. The form is essentially identical to the Interior Connected Lighting Power form discussed previously, except that entries in this table are limited to equipment permitted by § 9.6.3 of the Standard.

ID: Enter a code number or ID that is consistent with the lighting schedule on the plans and specifications. This identification should enable a plan checker to identify the location of luminaires of this type on the plans. This ID is also entered on the Additional Interior Lighting Power Allowance section of this form.

Luminaire Description: Provide a description of luminaire including information such as the number of lamps, watts per lamp, type of ballast, and type of fixture.

Type: Select one column to indicate the type of lighting source used for this luminaire. The choices are incandescent, fluorescent, HID, line-voltage track, low-voltage track, and other.

Number of Luminaires: Enter the number of luminaires of this type that are used for the special purpose.

Watts/Luminaire: Enter the total watts of power per luminaire. Be sure to include consideration of the ballast and any other factors that affect input power.

Total Watts: Calculate the total watts of power for this luminaire by multiplying the power per luminaire times the number of luminaires. This column should be summed and the total entered at the bottom of this form.

Exterior Building Lighting Power Allowance (Tradable Lighting Applications)

Use this table to calculate the lighting power allowance for exterior lighting in tradable applications. For each of the tradable lighting applications listed in Table 9.4.5 that occur in the project, enter

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the application type (e.g. building entrance with canopy), enter the allowance from Table 9.4.5, enter the linear feet or square feet as appropriate, multiply the allowance times the area or length, and enter that result in the Tradable Power Allowance column.

Exterior Building Lighting Power Allowance (Non-Tradable Lighting Applications)
This table is identical to the previous table except that the non-tradable lighting applications, as listed in Table 9.4.5, are to be entered here.

Additional Unrestricted Exterior Lighting Power Allowance
Enter the total power allowances from the preceding two tables, and multiply their sum by 5% to calculation the additional unrestricted exterior lighting power allowance. This value may be applied in the Exterior Lighting Compliance Test.

Exterior Connected Lighting Power (Tradable Applications)
Use this table to list the lighting equipment used for exterior lighting used for tradable applications as identified in Table 9.4.5.

ID: Enter a code number or ID that is consistent with the lighting schedule on the plans and specifications. This identification should enable a plan checker to identify the location of luminaires of this type on the plans.

Luminaire Description: Provide a description of luminaire including information such as the number of lamps, watts per lamp, type of ballast, and type of fixture.

Number of Luminaires: Enter the number of luminaires of this type that are used for the allowances listed above. For example, if the same type of luminaire is used for pathway lighting and entrance lighting, count only the luminaires that are used for entrance lighting in this table, since the Standard does not apply to pathway lighting.

Watts/Luminaire: Enter the total watts of power per luminaire. Be sure to include consideration of the ballast and any other factors that affect input power.

Total Watts: Calculate the total watts of power for this luminaire by multiplying the power per luminaire times the number of luminaires.

Exterior Connected Lighting Power (Non-Tradable Applications)
This table is similar to the preceding table except that the lighting application needs to be identified along with its corresponding luminaires because each of the non-tradable applications must comply individually.

Exterior Lighting Compliance Test
Each of the conditions in this table must be met for exterior lighting systems to comply. The tradable exterior lighting applications comply if the connected lighting power is no greater than the total allowance. All or a portion (or none) of the five percent additional allowance can be used to achieve compliance.

Connected lighting power for each of the non-tradable applications must be no greater than their corresponding allowances. Here additional allowance from the five percent pool can be applied to achieve compliance. The total of additional allowances used for both the tradable and non-tradable applications must be no greater than the total Additional Unrestricted Exterior Lighting Power Allowance.

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Lighting Compliance Documentation

Project Name:	
Project Address:	Date:
Designer of Record:	Telephone:
Contact Person:	Telephone:
City:	

Mandatory Provisions Checklist

Automatic lighting shutoff controls are provided based on either a scheduling device or an occupant sensor.

- ❑ Exception: Space is intended for 24-hour operation.
- ❑ Exception: Space is smaller than 5,000 ft².
- ❑ Exception: Space for patient care.
- ❑ Exception: Space where automatic lighting shutoff would endanger safety or security.

- ❑ Each space enclosed by ceiling-height partitions has an independent, accessible control that operates general lighting in the space.
  - ❑ Exception: The control is located in a remote location for safety or security reasons.
- ❑ For spaces less than or equal to 10,000 ft², a separate space control is provided for each 2,500 ft² of area.
- ❑ For spaces more than 10,000 ft², a separate space control is provided for each 10,000 ft² of area.
- ❑ Either a photosensor or an astronomical time switch controls exterior lighting applications.
  - ❑ Exception: Lights must remain on for safety, security or eye adaptation reasons.

- ❑ Two-lamp tandem-wired ballasts.
- ❑ Display lighting has a separate control.
- ❑ Case lighting has a separate control.
- ❑ Hotel/motel guest rooms have a master switch at the main entry.
- ❑ Task lighting has a separate control.
- ❑ Nonvisual lighting has a separate control.
- ❑ Demonstration lighting has a separate control.
- ❑ Exit signs do not exceed 5 W per face.
- ❑ Exterior building grounds luminaires greater than 100 W have lamps with minimum efficacy of 60 lumens/W.
  - ❑ Exception: Luminaire is activated with a motion sensor.

Interior Lighting Power Allowance (Building Area Method)

Building Type	Lighting Power Density (W/ft²)	Building Area (ft²)	Lighting Power Allowance (W)
		Total	

Interior Lighting Power Allowance (Space-by-Space Method)

Building Type	Common/Specific Space Type	Lighting Power Density (W/ft²)	Space Area (ft²)	Lighting Power Allowance (W)
			Total	

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Lighting Compliance Documentation

Project Name:	
Contact Person:	Telephone:

Interior Connected Lighting Power

ID	Luminaire Description (including number of lamps per fixture, watts per lamp, type of ballast, type of fixture)	Type						Number of Luminaires	Watts/ Luminaire	Total Watts
		Incandescent	Fluorescent	HID	Line-Voltage Track	Low-Voltage Track	Other			
		❍	❍	❍	❍	❍	❍

Lighting Compliance Documentation

Project Name:	
Contact Person:	Telephone:

Additional Interior Connected Lighting Power

ID	Luminaire Description (including number of lamps per fixture, watts per lamp, type of ballast, type of fixture)	Type						Number of Luminaires	Watts/ Luminaire	Total Watts
		Incandescent	Fluorescent	HID	Line-Voltage Track	Low-Voltage Track	Other			
		❍	❍	❍	❍	❍	❍			
		❍	❍	❍	❍	❍	❍			
		❍	❍	❍	❍	❍	❍			
		❍	❍	❍	❍	❍	❍			
		❍	❍	❍	❍	❍	❍			
		❍	❍	❍	❍	❍	❍			
		❍	❍	❍	❍	❍	❍			
		❍	❍	❍	❍	❍	❍			
		❍	❍	❍	❍	❍	❍			
									Total	

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Lighting Compliance Documentation

Exterior Building Lighting Power Allowance (Tradable Lighting Applications)

Application	Allowance	Area or Length (ft² or ft)	Tradable Power Allowance
		Tradable Power Allowance	

Exterior Building Lighting Power Allowance (Non-Tradable Lighting Applications)

ID	Application	Allowance per Unit	Area or Length or Quantity	Non-Tradable Power Allowance
			Non-Tradable Power Allowance	

Additional Unrestricted Exterior Lighting Power Allowance

Tradable Power Allowance (Watts)		Non-Tradable Power Allowance (Watts)			Additional Unrestricted Lighting Power Allowance (Watts)
(	+	)	X 0.05	=	

Exterior Connected Lighting Power (Tradable Applications)

ID	Luminaire Description (including number of lamps per fixture, watts per lamp, type of ballast, type of fixture)	Number of Luminaires	Watts/ Luminaire	Total Watts
			Total	

Exterior Connected Lighting Power (Non-Tradable Applications)

ID	Non-Tradable Application	Luminaire Description (including number of lamps per fixture, watts per lamp, type of ballast, type of fixture)	Number of Luminaires	Watts/ Luminaire	Total Watts

Exterior Lighting Compliance Test

	Tradable Power Allowance (Watts)		Additional Unrestricted Lighting Allowance to be Applied (Watts)		Tradable Connected Lighting Power (Watts)
		+		≥	
Non-Tradable Application	**Non-Tradable Power Allowance (Watts)**				**Non-Tradable Connected Lighting Power (Watts)**
		+		≥	
		+		≥	
		+		≥	
			Total Additional Allowance Applied (sum of above) (Watts)		Additional Unrestricted Lighting Power Allowance (Watts)
				≥	

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10. Other Equipment

General Information (§ 10.1)

General Design Considerations

Section 10 of the Standard covers electric motor efficiency requirements. Compliance with this section is the responsibility of equipment manufacturers and importers, not the responsibility of designers and builders. These efficiency requirements are part of Federal law in the United States and have been in effect since October 1997 (in a few special applications, the requirements took effect in October 1999). Therefore, all motors purchased in the United States should already comply with the requirements of the Standard.

In motors, the electrical energy not converted to motion is dissipated as heat, and that waste heat may account for 5% to 20% of the energy used by a typical HVAC motor. In the case of most fan motors, that heat must be removed by the air conditioner, causing additional energy consumption. While a motor specifier need not worry about compliance, she should consider motors that exceed the minimum efficiencies required by the Standard.

The requirements listed in Table-A correspond to the "energy efficient" category as defined by the National Electrical Manufacturers' Association (NEMA). "Premium efficiency" motors are roughly 5% more efficient than required by the Standard and will usually be cost-effective in cases where motors run at least 500 hours each year (such as most pumps and fans in HVAC applications).

Scope (§ 10.1.1)

The requirements of § 10 are Mandatory Provisions that must always be met, even if the energy cost budget (ECB) method is used. These Mandatory Provisions apply to electric motors used for all building applications. This means that in addition to motors for HVAC and water heating uses, the requirements apply to motors used for applications such as elevators, escalators, domestic water pumps, fire pumps, and sewage ejector pumps.

Inch-Pound and Metric (SI) Units

The Standard is available in two versions: an inch-pound (I-P) version and a metric (SI) version. This chapter works with both versions. Horsepower to watts or kW is the only necessary conversion, which is given below.

I-P Units		**SI Units**
hp	× 0.7457	= kW
hp	× 745.7	= W

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Mandatory Provisions (§ 10.4)

The types of motors covered by the Standard are defined by the Energy Policy Act of 1992. They include most general-purpose motors used in building applications,[10] and meet one or more of the following criteria:

- Size 1 to 200 hp.
- Three-phase, 60Hz, 230, or 460 volts.
- Single-speed.
- Can be used in most general applications.
- Open drip-proof (ODP) or totally enclosed fan-cooled (TEFC).
- Design A and Design B motor types. (These refer to the motor's torque characteristics and are NEMA classifications. Design A and B have locked-rotor torque between 70% and 275% of full load torque. Other types of motors have higher locked-rotor torque and are not common in HVAC applications.)

Any other type of motor is not covered by the Standard. In many cases, these motors are exempt because they serve a special purpose and are not appropriate for general building system use. Others are not covered because they are not common in building applications or they have a small energy impact. If a motor meets any one or more of the following criteria, then it is exempt from the Standard's efficiency requirements:

- Smaller than 1 hp or larger than 200 hp;
- Single-phase power;
- 120 volts, 208 volts;
- Without feet or without provision for feet;
- Multi-speed (e.g., two-speed);
- Close-coupled pump motor;
- Totally enclosed nonventilated motor;
- Totally enclosed air-over motor (requires external fan);
- Integral gear motor.

10. U.S. Department of Energy policy statement, Federal Register 62FR59977, November 5, 1997.

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The only requirement of § 10.4 is a minimum efficiency rating that depends on the motor size, type, and speed. Table 10-A (Table 10.8 of the Standard) lists those requirements.

The motor size is listed in Table 10-A as "Motor Horsepower," that is, the nominal horsepower shown on the motor nameplate.

The requirements also depend on whether the motor type is open or enclosed. Both types are used in HVAC applications. The choice depends on the environment; enclosed motors are often used in conditions where a motor might get wet.

The efficiency requirements also depend on the rotation speed of the motor. The speed is determined by the motor's construction. If a motor has one pair of north/south poles for each of the three-voltage phases, then it is called a two-pole motor. With 60 Hz power and no load, a two-pole motor rotates at 3,600 rpm, its synchronous speed. Adding more poles slows the speed of the motor. A four-pole motor rotates at 1,800 rpm and a six-pole motor at 1,200 rpm. Note that a motor's actual speed will be slightly less than its synchronous speed. For example, a four-pole motor will have a nominal speed of about 1,750 rpm when under load.

Table 10-A—Minimum Nominal Efficiency for General Purpose Design A and Design B Motors

(This is Table 10.8 in the Standard)

	Minimum Nominal Full-Load Efficiency (%)					
	Open Motors			Enclosed Motors		
Number of Poles ==>	2	4	6	2	4	6
Synchronous Speed (RPM) ==>	3,600	1,800	1,200	3,600	1,800	1,200
Motor Horsepower						
1 (.8 kW)	-	82.5	80.0	75.5	82.5	80.0
1.5 (1.1 kW)	82.5	84.0	84.0	82.5	84.0	85.5
2 (1.5 kW)	84.0	84.0	85.5	84.0	84.0	86.5
3 (2.2 kW)	84.0	86.5	86.5	85.5	87.5	87.5
5 (3.7 kW)	85.5	87.5	87.5	87.5	87.5	87.5
7.5 (5.6 kW)	87.5	88.5	88.5	88.5	89.5	89.5
10 (7.5 kW)	88.5	89.5	90.2	89.5	89.5	89.5
15 (11.1 kW)	89.5	91.0	90.2	90.2	91.0	90.2
20 (14.9 kW)	90.2	91.0	91.0	90.2	91.0	90.2
25 (18.7 kW)	91.0	91.7	91.7	91.0	92.4	91.7
30 (22.4 kW)	91.0	92.4	92.4	91.0	92.4	91.7
40 (29.8 kW)	91.7	93.0	93.0	91.7	93.0	93.0
50 (37.3 kW)	92.4	93.0	93.0	92.4	93.0	93.0
60 (44.8 kW)	93.0	93.6	93.6	93.0	93.6	93.6
75 (56.0 kW)	93.0	94.1	93.6	93.0	94.1	93.6
100 (74.6 kW)	93.0	94.1	94.1	93.6	94.5	94.1
125 (93.3 kW)	93.6	94.5	94.1	94.5	94.5	94.1
150 (111.9 kW)	93.6	95.0	94.5	94.5	95.0	95.0
200 (149.2 kW)	94.5	95.0	94.5	95.0	95.0	95.0

Note: Nominal efficiencies shall be established in accordance with NEMA Standard MG1. Design A and Design B are Natiional Electric Manufacturers Association (NEMA) design class designations for fixed frequency small and medium AC squirrel-cage induction motors.

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11. Energy Cost Budget Method

General Information (§ 11.1)

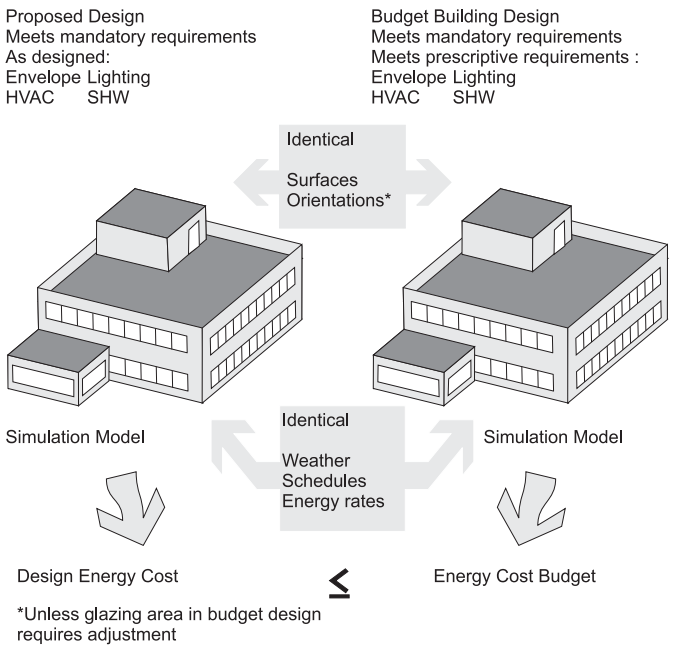

Figure 11-A—Compliance through ECB Method, New Building

This chapter describes the Energy Cost Budget (ECB) method, and explains how to use this alternative approach to demonstrate compliance with the Standard.

With the ECB method, a computer program is used to calculate the design energy cost for the proposed building design and to calculate the energy cost budget for a budget building design. In the budget building design, which is a variant of the proposed building design, all mandatory and prescriptive requirements of the Standard are applied. In other words, the energy cost budget represents the building as if it complied with the Standard. The design energy cost for the proposed design cannot exceed the energy cost budget. Figure 11-A illustrates how compliance can be achieved by using the ECB method for a proposed new building.

As discussed throughout this Manual, in order to obtain a building permit in a jurisdiction that has adopted the Standard, the building designers must demonstrate to the authority having jurisdiction (the building officials) that the design meets the Standard's requirements. The previous chapters reviewed the General and Mandatory Provisions of the Standard with which the building's design must comply. In addition, the previous chapters described the prescriptive requirements of the Standard by building system: envelope, HVAC, lighting, etc.

These prescriptive requirements guide the system designer in specifying efficient components, controls, and other features, but these requirements are not interrelated between systems. In all buildings, however, the energy systems interact with each other in ways that affect their performance. For example, if you reduce the lighting power, typically the cooling loads decrease and the heating loads increase. In many buildings, it makes sense to look at the overall performance of the building as an integrated system and to make decisions that optimize the design based on interactions among its systems. One reason for using the ECB method is that it allows designers to evaluate the overall performance of their buildings in terms of energy cost.

Another reason to use the ECB method is to make trade-offs between systems. A designer might decide, for example, to design some of the energy systems to be less efficient than allowed under the prescriptive requirements in order to achieve a particular design objective. If other systems are made more efficient than the prescriptive requirements, however, the overall energy cost of the building could be as low as it would be if all the systems met the prescriptive requirements. Under the ECB Method, the designer could demonstrate this performance level and so comply with the Standard.

The reasons that a designer might choose to make some systems less efficient are as varied as the design objectives for a particular building. The design team might decide, based on the economics or aesthetics of their project, to build it differently than the prescriptive requirements allow. For example, a building might use a type of wall or roof construction that is difficult to insulate. Or an owner might want large areas of clear

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glass to take advantage of special views. Or a lighting designer might desire extra lighting power to achieve a special look in major building spaces. Or a mechanical engineer might select a less efficient type of boiler in order to maintain consistency with an existing boiler plant. The ECB method provides the building owner and design team with the flexibility to make these kinds of trade-offs, provided the end result is a building that does not have higher annual energy costs than it would if it met all the prescriptive requirements.

Scope and Limitations (§ 11.1.1, § 11.1.2 and § 11.1.3)

In general, the ECB method may be used to show compliance with the Standard for any project at the designer's discretion, subject to the limitations on the scope of the Standard discussed in Chapter 2. There are, however, some exceptions specific to the ECB Method:

- *No Mechanical System:* Use of the ECB method requires knowledge of the proposed mechanical system in order to determine the budget building system. Buildings with no mechanical system cannot use the ECB Method. There is really no reason to use the ECB Method for these buildings because there are no requirements under the Standard for unconditioned spaces. In the case of a shell building, which might become conditioned in the future, trade-offs may still be made within the envelope system, using the EnvStd software, or within the lighting system LPD allowance, but the ECB Method may not be used.
- *No Envelope Design*: New buildings or additions that do not have an envelope design ready for submittal to the building official for permit approval cannot use the ECB method (see § 11.1.3). The building envelope must first be designed so that the ECB calculations can account for its characteristics. In other words, ECB cannot be used to obtain permit approval for a mechanical or lighting system prior to the submittal of the envelope design for approval. In the case of a newly conditioned space or a gut rehab where the existing envelope is not being changed or is not part of the permit, then the rules for alterations apply; the envelope would be modeled as-is and would be the same for both the proposed and budget building design runs (see following discussion).

Special Cases for Nonresidential Buildings

Some special cases arise with nonresidential buildings because they are often built in stages. A shell building, for example, has an envelope design that may be constructed before the lighting, HVAC, and other systems are designed. The occupancy may be unknown at this stage; it may not even be known if the building will become conditioned space. It is also common to have buildings with envelope, mechanical, power, and service water-heating systems installed but with the lighting system design and installation left for future tenant improvements. In these cases, there will be two or more building permits issued to cover the separate system designs, and the application of the ECB method follows some special rules:

- *Existing Systems (§ 11.1.2):* The energy performance of an existing system is not available for trade-off. Existing systems are modeled identically in determining the energy cost budget and the design energy cost. This has the effect of locking in the existing system efficiencies. Experience has shown that determining and documenting the performance of the existing systems is difficult and can lead to abuses in compliance.
- *Future Systems (§ 11.1.2 and Table 11.3.1-1a)*: The energy performance of a future system is not available for trade-off. Future, yet-to-be-designed systems are modeled as if they meet the mandatory and prescriptive requirements of the Standard. This prevents designers from making promises of higher efficiency in future systems in order to build less efficient systems in the present. Experience has shown that these promises are difficult to enforce and may place an unexpected constraint on the designers of those future systems. These promises can also lead to gamesmanship in compliance. (Gamesmanship, in the sense of this discussion, is the practice of generating an undeserved trade-off credit by artificially manipulating the ECB method to circumvent the Standard's intent.)
- *Systems Submitted for Permits at the Same Time*: The consequence of the preceding two rules is that designers may only make trade-offs if the affected systems are submitted for permit approval together. An owner who wishes to make trade-offs between the lighting system and the building envelope must design them together and submit them under the same permit application, rather than building them in stages.
- *Additions (§ 4.2.1.2)*: These are subject to the same rules discussed above. This means that trade-offs may only be made among the systems in the same permit application. As a special case, if an addition is done at the same time as changes are made to the existing building, then trade-offs are allowed among all the new or altered systems (see Special Case for Additions).
- *Alterations (§ 4.2.1.3)*: Likewise, in an alteration, trade-offs may only be made among the systems that are being altered. This usually occurs only with a gut rehab or other major alteration project; minor alterations do not encompass enough systems to make the ECB trade-off procedure practical.

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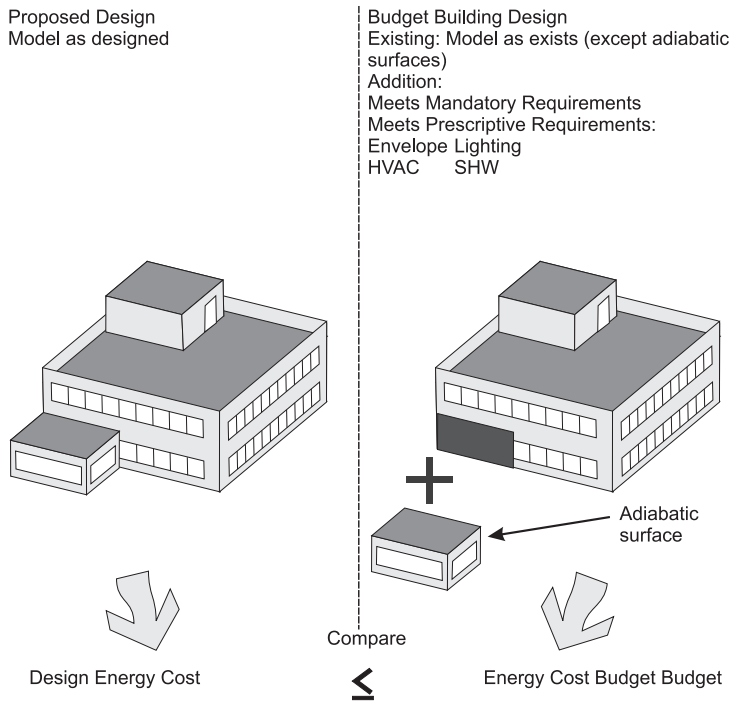

Figure 11-B—Compliance through ECB Method, Existing Building with Addition

Special Case for Additions

There is a special case for additions under the ECB method. Normally, an addition is treated under the Standard as if it were a new, stand-alone building, and it may comply under either the prescriptive approach or under a trade-off procedure known as the "addition + existing trade-off" (exception to 4.2.1.2).

If an addition to an existing building cannot comply with the Standard on its own, then improvements to the existing building may be made to offset the inefficiencies of the addition. In effect, trade-offs can be made between the energy performance of the existing building and the addition. If the energy *consumption* of the proposed addition and the altered existing building is less than energy budget, the design complies.

The addition and any changes to the existing building must, of course, meet the General and Mandatory Provisions of each section in the Standard.

The ECB method provides a clearly defined calculation procedure for the "addition + existing trade-off" but the Standard allows the designer to use any kind of energy analysis calculation that is acceptable to the authority having jurisdiction. These would provide the basis for demonstrating that the "addition + existing" combination meets the Standard's requirements.

There is a special modeling consideration when preparing the simulation models for the "addition + existing trade-off" procedure. The surface of the existing building that the addition abuts is treated as existing exterior surface area in the budget building design and as interior surface area (or empty space) in the proposed design. The corresponding surface of the addition is treated as the same in both cases. If the addition and the adjoining existing space are similar, this surface of the addition may be treated as an adiabatic surface (i.e., a surface with no heat transfer through it). If conditions in the addition and the adjoining existing space are different, so that there would be significant energy flows into or out of the addition, then the simulation model for budget building design for the addition should include an adjoining space that will allow these energy flows to be accounted for in the addition's energy budget.

Alterations to Existing Buildings

When the ECB method is used for an alteration of an existing building, some special rules apply (see exceptions to 4.2.1.3).[11] The ECB Method is optional for this purpose; designers may use any calculation method acceptable to the authority having jurisdiction. Unless a building component is being altered, the proposed design model and the budget model are identical for that component. Portions of the building that are being replaced shall be treated as new systems and these systems in the budget model shall be representative of the requirements in the Standard. However, there are some exceptions:

11. When the alterations are done under the "addition + existing" case, discussed in the previous section, the rules are different than when the project involves just alterations, as discussed in this section.

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- *Remodeled Opaque Envelope:* Remodeled wall, ceiling/roof, and floor having cavities for insulation will be described in the budget design model with the *higher* U-factor of the walls with their cavities filled with R-3 per inch of insulation (fiberglass, cellulose, or better) or to the insulation requirements of § 5.5.1. If remodeled floors and walls do not have framing cavities, model these components in the budget design with the *higher* U-factor of either the requirements in § 5.5.1 or the proposed design. If a roof membrane is replaced without exposing the insulation or there if there is existing insulation under the roof deck insulation, and no insulation is to be added, the roof shall be identical in both the budget and proposed design models. (Note that insulation installed on a suspended ceiling with removable ceiling panels is not acceptable as under-roof deck insulation, per § 5.8.1.8.)
- *Replacement Glazing or Storm Windows*: Replacement glazing in the existing sash and frame shall be described in the budget design model as glazing with U-factors and solar heat gain coefficients (SHGC) that are identical to the properties of the pre-existing glazing. When the entire window is replaced, the glazing U-factor and SHGC in the budget model will be equal to the maximum values allowed by § 5.5.4.1. When storm windows are proposed over existing windows, the budget building will be modeled with the original windows.
- *New Light Fixtures:* Replacement lighting systems in the budget model must meet the lighting power density requirements in § 9.3 for each enclosed space (room) where 50% or more of the luminaires will be replaced. Spaces where less than 50% of the luminaires will be replaced will be modeled with its existing lighting power density before replacement.

Compliance (§ 11.1.4)

This chapter discusses how to ensure that the calculations produce a fair comparison between the two designs, as well as when and how trade-offs may be made under the ECB method.

It's important to remember that the Standard's Mandatory Provisions (§ 5.4, 6.4, 7.4, 8.4, 9.4, and 10.4) are not available for trade-off under the ECB method. The building design must meet or exceed all the requirements of the Mandatory Provisions. There are many reasons for this.

- Some of the Mandatory Provisions, such as minimum motor efficiencies, are standard good practice and they should always be used.
- Some are difficult to accurately model in a computer simulation, such as subdivision of feeders, and so their trade-off value cannot be accurately determined.
- Some specify calculation methodologies needed to establish a fair basis for comparison of components, such as U-factor calculations.
- Some Mandatory Provisions are not intended for trade-offs, such as exterior lighting.

Showing that the proposed design meets the requirements of the mandatory provisions and the ECB method is necessary but not sufficient to comply with the Standard. It is also necessary that the building be built to the efficiency levels modeled by the proposed design. This means that the efficiency of the individual components, the operation of the controls, and the overall design of the building must conform to the proposed design that was used to calculate the design energy cost. For this to happen, the building designers must accurately translate the energy assumptions used in the design energy cost calculations into the plans and specifications used to construct the building. The building official (that is, the authority having jurisdiction) will verify during plan check that this has occurred and will also verify during field inspection that the building is built to those specifications. The ECB Method has several features, discussed in following sections of this chapter, that support this process.

Disclaimer

It is important for users of the ECB method, as well as the owners of the proposed buildings, to understand the ECB Method's intent and limitations. It is intended to provide a fair method of comparison between the estimated annual energy cost of the proposed design and the budget building design for purposes of compliance with the Standard. The ECB Method is not intended to provide the most accurate prediction of actual energy consumption or costs for the building as it is actually built.

Although the designer is expected to model the future use of the building as closely as possible, there are many reasons why the actual building performance may differ from the design energy cost and consumption. These include:

- *Variations in Occupancy:* The actual schedules of operation and occupancy may differ from those assumed in the ECB analysis.
- *Variations in Control and Maintenance:* The building's energy systems may be controlled differently than assumed; the equipment may not be set up or maintained properly.
- *Variations in Weather*: The simulation runs use weather data that may not match the actual weather conditions; further, there is variability in weather conditions from year-to-year.
- *Energy Uses not Included*: The ECB method does not require all building energy uses to be included in calculating

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the design energy cost, and there is often additional energy-using equipment added to a building after it is built.

- *Changes in Energy Rates*: The electricity, gas, and other energy rates assumed in the calculations may change over time, resulting in higher or lower actual energy costs.
- *Precision of the Simulation Program*: Even the most sophisticated simulation programs approximate the actual energy flows and consumption in a building; further, the energy analyst will usually make simplifying assumptions. Both can be sources of error in the predictions of energy cost and consumption.

The ECB method relies on the energy analyst and building designers to make reasonable assumptions for these factors, and the design energy cost and consumption are expected to be reasonable predictions, especially since this is a comparative analysis and the proposed design and budget building use similar assumptions. However, it is clear from the points listed on page 11-2, that even the best set of assumptions will likely lead to predictions that differ from actual building performance.

Documentation Requirements (§ 11.1.5)

When a building design is submitted to the authority having jurisdiction (typically the building official) for a plan check and a permit, the designers must include documentation demonstrating that the design meets the Standard's requirements. If the ECB method is used, there are some special documentation requirements intended to help the building official verify that the ECB Method rules have been followed. The documentation requirements are described below.

Summary
This is a summary of how the design energy cost compares to the energy cost budget. The compliance form at the end of this chapter may be used for this purpose.

Energy-Related Features
This is a list of the proposed design's energy-related features that exceed the Standard's requirements, as well as a list of those features that are being traded off. These features will have been modeled in the simulation program, and so it is necessary that they be included in the actual building if the design energy cost is to be accurate. If they are not included in the building, the building will not comply with the Standard. It is therefore necessary that the features be clearly described in the compliance documentation, and that they be clearly indicated on the building's plans and specifications. Also, all features that are modeled differently between the energy cost budget and the design energy cost must be listed and specified.

Input/Output Reports
The input and output reports from the simulation program must be submitted, including a breakdown of energy usage by at least the following components: lights, internal equipment loads, service water heating equipment, space heating equipment, space cooling and heat rejection equipment, fans, and other HVAC equipment (such as pumps). These numbers help to explain how the building is energy efficient and where the priorities for efficiency are found in the design. In addition, the output reports must show the amount of time any loads are not met by the HVAC system for both the proposed design and the budget building design. If there is a substantial discrepancy between these two values, then the simulation models are not satisfactory (see Error Messages).

Error Messages
Provide an explanation of any error messages, warnings, or exceptions noted in the simulation program output. These messages indicate possible problems with the simulation models for the two designs, or they may simply indicate special conditions in the buildings. The burden is on the simulation modeler to explain which of these two conditions is indicated by each error message and to establish to the building official's satisfaction that the models adequately demonstrate compliance under the ECB method.

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Simulation General Requirements (§ 11.2)

At the heart of the ECB method lie the calculations done by a simulation program to demonstrate that the proposed design complies with the Standard. In order to make sure that these calculations are sufficiently accurate for the purposes of the Standard, a series of requirements have been set.

The most basic requirement is that the simulation program be a computer-based program designed to analyze energy consumption in buildings, and that it have the capability to model the performance of the proposed design's energy features. ECB calculations are too complex for hand calculations, but there are many computer programs available that have the needed capabilities and are in widespread use. Examples include DOE-2 and BLAST, which were developed largely with public funds, and which are available to users in both public and private sector versions. Several other proprietary programs also exist that have the minimum capabilities required by the Standard. A listing of simulation tools that may be suitable for the ECB Method can be found on the U.S. Department of Energy's web site at **Error! Hyperlink reference not valid.**.

Minimum Modeling Capabilities (§ 11.2.1)

Section 11.2.1 specifies a minimum set of capabilities for ECB method simulation programs. These have been broadly defined to allow all capable programs to be considered for approval by the adopting authority, while eliminating programs that would not be able to adequately account for the energy performance of building features important under the Standard. These minimum capabilities are:

1. *Minimum Hours per Year*: Programs must be able to model energy flows on an hourly basis for at least 1,400 hours per year. Many programs model for the full 8,760 hours in a year; others use representative days for the different months and seasons.

2. *Hourly Variations:* Building loads and system operations vary hour-by-hour, and their interactions have a great influence on building energy performance. Approved programs must have the capability to model hourly variations—and to establish separately designed schedules of operation for each day of the week and for holidays—for occupancy, lighting power, miscellaneous equipment power, thermostat set points, and HVAC system operation.

3. *Thermal Mass Effects*: A building's ability to absorb and hold heat varies with its type of construction and with its system and ventilation characteristics. This affects the timing and magnitude of loads handled by the HVAC system. Simulation programs must be able to model these thermal mass effects.

4. *Number of Thermal Zones*: There are multiple thermal zones in all but the simplest buildings, and they experience different load characteristics. Approved programs must be able to model at least 10 thermal zones; many simulation programs can handle far greater number of zones.

5. *Part-Load Performance*: Mechanical equipment seldom experiences full-load operating conditions, so the performance of this equipment under part-load conditions is important. Approved programs must incorporate part-load performance curves in their calculations.

6. *Correction Curves*: Mechanical equipment capacity and efficiency varies depending on temperature and humidity conditions. Approved programs must incorporate capacity and efficiency correction curves for mechanical heating and cooling equipment.

7. *Economizers*: Economizer cooling is an important efficiency measure under the Standard. Approved programs must have the capability to model both airside and waterside economizers with integrated control. This means that the economizer model must be able to credit economizer cooling for meeting the cooling load even when it must work in tandem with the mechanical cooling system to do so.

8. *Budget Building Design Characteristics*: In addition to the general capabilities described above, simulation programs must have the capabilities to model the budget building design, as specified in § 11.3 and discussed in Calculation of Design Energy Cost and Energy Cost Budget (§ 11.3). This is to ensure that the program can properly calculate the energy cost budget.

9. *Energy Costs*: In addition to calculating energy use in the building, the simulation program must be able to calculate the energy cost, based on approved purchased energy rates. This may be done either directly within the program, or as a side calculation. If done as a side calculation, the program must be capable of producing hourly reports of energy use by energy source, to which the approved purchased energy rates can be applied. This capability must be available for both the energy cost budget and the design energy cost calculations.

10. *Design Load Calculations*: Approved programs must be capable of performing design load calculations to determine required HVAC equipment capacities and air and water flow rates (in accordance with § 6.4.2 of the Standard) for both the proposed design and the budget building design. This is to ensure that the systems in both design simulations are properly sized, which avoids the problem of differing part-load performance characteristics between the

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two designs. As discussed in Equipment Sizing (§ 11.3.2i), the sizing ratio for the budget building run must be similar to the actual sizing ratio for the proposed design run, based on design load calculations.

Testing of Simulation Program (§ 11.2.1.4)

"The simulation program shall be tested according to ANSI/ASHRAE Standard 140-2004 and the results shall be furnished by the software provider." This procedures requires that the simulation tool perform standardized tests and that the results be compared to other calculation engines. There is no pass/fail requirement, just that the tests be performed.

Climatic Data (§ 11.2.2)

Climatic data must be approved by the authority having jurisdiction, although it is recommended that the adopting authority pre-approve climate data sets for use with the ECB method. The climate data must provide hourly values for all the relevant parameters needed by the simulation program, such as temperature and humidity. In addition, data on solar energy, cloudiness, wind, etc., are often used by the programs.

Because the simulations are meant to represent the building's long-term energy performance, it's important that the climate data represent both average and design conditions. The average conditions alone are not sufficient because equipment-sizing calculations need data on design weather conditions. In some cases, this can be handled by using average weather data for annual simulations but using design hour or day data for equipment sizing purposes.

For small jurisdictions, such as a single city, there may be only one weather data set required. For larger jurisdictions, several may be required. California, for example, has been divided into 16 different climate zones, each with its own climate data. If the adopting authority has not pre-approved climate data for use with the ECB method, then the energy analyst may obtain appropriate climate data and submit it for approval to the authority having jurisdiction (typically the local building official). Whatever the source, there is frequently a need to apply engineering judgment in selecting climate data because weather stations having full data collection capabilities are not always located close to the subject building site. In this case, the closest available weather station data should be used. Closest may not always mean geographic proximity, however. Major terrain features, such as elevation or mountains or seashore, could affect the choice of climate data set. The objective is to best approximate the weather conditions that will be experienced at the building site.

Purchased Energy Rates (§ 11.2.3)

Purchased energy rates for electricity, gas, oil, propane, steam, or chilled water must be approved by the adopting authority, as discussed in the Adoption Considerations section at the end of this chapter. The energy analyst may be left with some latitude to choose between different rates or rate structures, but the choice should best represent the purchased energy rates that will apply to the building over its lifetime. The actual purchased energy rates offered by local energy suppliers may differ from the rates used for ECB calculations. In this case, the designers and owner may want to do their own evaluation of the cost-effectiveness of the various building features. This may lead them to adjust the design to better meet their needs. Nevertheless, the final ECB compliance simulations must be done using the approved purchased energy rates. This ensures consistent application of the Standard within the jurisdiction.

On-Site Renewable or Site-Recovered Energy

There is a special case for calculating the design energy cost for buildings that have on-site renewable energy sources or site-recovered energy. For example, a building may have a solar thermal array, photovoltaic panels, or access to a geothermal energy source. Or a building with substantial refrigeration loads may recover heat from the condenser to meet service water heating loads. If either renewable or recovered energy is available at the site, it is considered free energy by the ECB method, and that energy is not included in the design energy cost (provided that it is not required by any of the mandatory or prescriptive requirements, such as in § 6.5.6, Energy Recovery). For the energy cost budget calculations, the loads met by renewable or recovered energy are considered to be served by the backup energy source. For example, where recovered energy is used to heat water (and this is not required by § 6.5.6.2), then the backup water heater would be assumed to supply all the hot water for the budget building design, and that cost would be part of the energy cost budget. If no backup energy source is specified for the proposed design, then the source is assumed to be electricity in the budget building design, and the approved purchased electricity rates are used to calculate that component of the energy cost budget.

Compliance Calculations (§ 11.2.4)

The deciding step in the ECB method is the calculation and comparison of the energy cost budget and the design energy cost (which may not exceed the budget). The following sections cover the details

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about how these two simulation runs are to be done, but there are four general rules that always apply:

1. Both runs must use the same simulation program.
2. Both runs must use the same climate data.
3. Both runs must use the same purchased energy rates.
4. Both runs must use the same schedules of operation.

These rules ensure a fair comparison between the two runs, without introducing extraneous differences. For instance, if the runs used different simulation programs, then some portion of the differences between the resulting energy costs would be due to differences in algorithms or calculation methodologies. These differences could skew the determination of which building features are allowable under the Standard. Similarly, if two different purchased energy rates were used, part of the difference between the runs would be due to rate differences. While this may be real in particular applications, it would introduce variations in the efficiency requirements for the building that are inconsistent with the rest of the Standard. Furthermore, due to the changeable nature of purchased energy rates, these differences may not last for the life of the building and so could skew the design of the building's energy-related features. Individual building owners or designers may choose to optimize their buildings to take advantage of special rates, but the results must still pass the ECB method test using the same rate for both runs.

Exceptional Calculation Method (§ 11.2.5)

As newer technologies become available, there may be cases where none of the existing simulation programs can adequately model the energy performance of these technologies. The Standard allows the authority having jurisdiction the discretion to approve an exceptional calculation method for use with the ECB method. The nature of the exceptional method is open-ended, but the burden is on the applicant to demonstrate that the method is reasonable, accurate, well founded, and not in contradiction with the rules of the ECB Method. The applicant must describe the theoretical basis for the exceptional method and must provide empirical evidence that the method accurately represents the energy performance of the design, material, or device. This documentation must also show that the method and its results:

1. Do not change the simulation program input parameters that are constrained by the ECB method or any other rules of the adopting authority. For example, the exceptional method may not violate the rule against using different operating schedules for proposed and budget runs.
2. Provide adequate documentation for enforcement, including the assumptions and inputs to the method and the results and outputs of the method. As with the other aspects of the ECB method calculations, the results must produce clear and consistent reporting of the required equipment and system features so that the enforcement personnel can verify that the field installation has been done in accordance with the assumptions in the ECB analysis. The documentation should also be consistent with the other documentation requirements established by the adopting authority.
3. Provide instructions for the exceptional method, so that other users may apply it consistently and fairly in future ECB method applications. Once approved, the exceptional calculation method will become, in effect, an amendment to the ECB Method. An example of a change in the simulation program might be a new algorithm for ground source heat exchangers or a credit for occupancy sensors. The authority having jurisdiction is not discouraged from approving exceptional methods, but it should exercise judgment and care in approving them to ensure that they do not become substantial loopholes in the Standard.

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Calculation of Design Energy Cost and the Energy Cost Budget (§ 11.3)

The *design energy cost* is calculated by the simulation program based on the proposed design of the building in its final form, that is, the design submitted for building permit approval. For most new buildings, this is a straightforward exercise in modeling the building as it was designed, using good engineering judgment and the capabilities of the simulation program. All the building features shown in the design documents, including building size and shape, building envelope components and assemblies, lighting, water heating, and mechanical system equipment and controls, must be accounted for. The rules for calculating the design energy cost in § 11.3 deal primarily with special circumstances and exceptions.

The *energy cost budget* establishes the energy efficiency target for the building. It is the estimated annual energy cost for the budget building design. The energy cost budget is compared to the design energy cost, which may not exceed the budget. The design energy cost and the energy cost budget are calculated as separate runs by an approved simulation program using the rules spelled out in the Standard.

The most important thing for a designer to understand about the ECB method is how the two simulation runs differ from each other; it is these differences that determine the trade-offs between measures and determine whether the proposed design complies with the Standard. Many, if not most, of the inputs to the two simulation runs are identical. These identical building features and operational characteristics are "energy neutral," i.e., they produce no energy credits or debits that could affect the overall building energy performance. The features that are different may result in savings or increases in energy cost, and so these differences are the ones that determine compliance.

The following sections describe how the budget building design is derived for each of the major systems. For new buildings, the basic concept is that the budget design is the same as the proposed design, except that each of the components is assumed to just meet the applicable prescriptive requirements of the Standard. For existing building spaces, new system components are assumed to meet the prescriptive requirements, while unchanged components are modeled at their existing levels of energy performance. There are special cases that are covered with special rules, but the basic concept is just that simple.

Design Model (Table 11.3.1-1)

The proposed design and the corresponding budget building shall be consistent with information contained on the plans and specifications.

Some buildings, such as retail malls and speculative office buildings, typically are built in phases. For example, the core mechanical system may be installed with the base building, while the ductwork and terminal units are installed later as part of tenant improvements. A similar situation can occur with the lighting system or with the building's other energy-related features.

This situation was discussed in general terms above (see When the ECB Method May Be Used). For the purpose of calculating the design energy cost, the rule is simple: future energy features that are not yet designed or documented in the construction documents are assumed to minimally comply with the applicable Mandatory Provisions and prescriptive requirements of the Standard, as specified in Sections 5 through 10. In cases where the space use classification is not known, the default assumption is to classify it as office space using the Building Area Method.

The ECB method, and indeed the rest of the Standard, is based on the assumption that nonresidential buildings are heated and cooled. Even if not installed initially, it is common for buildings lacking a heating or cooling system to have one retrofitted by future occupants. Accordingly, there is a special rule for calculating the design energy cost when a building's HVAC system is heating-only or cooling-only: the building must be modeled as if it had both heating and cooling. The missing system is modeled as the default heating or cooling system that just meets the Prescriptive Requirements of the Standard. The same system is modeled for both runs. (Specific details of these default systems are discussed in the following section on HVAC systems; also see Table G3.1-10 and § 11.3.2j in the Standard.) This requirement only applies to conditioned spaces in the building: semiheated spaces would only have a heating system; unconditioned spaces would have neither heating nor cooling systems.

Alterations and Additions (Table 11.3.1-2)

The basic rules for alterations and additions were discussed at the beginning of this chapter. There are some further rules that apply to cases where it is undesirable either to treat the addition as a stand-alone building or to fully model the entire existing building. It is often necessary with additions or alterations to model at least part of the existing building. For instance, if the existing building's HVAC system is being extended to serve

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the new construction, then that system needs to be fully modeled in order to account for its energy performance. If, however, this system only serves a portion of the existing building and only part of that building is influenced by the new work, then it is unnecessary to model the entire existing building.

The rules for excluding parts of the existing building are as follows.

1. If there is any new work covered by the Standard that is in a part of the existing building that will be excluded from the proposed design modeling, then those parts must comply with the Standard's applicable prescriptive requirements.
2. The excluded parts of the existing building must be served by HVAC systems that are completely independent of the systems or building components being modeled for the design energy cost.
3. There should not be any significant energy flows between the excluded parts of the building and the modeled parts. In other words, the design space temperature, HVAC system operating setpoints, and operating and occupancy schedules on both sides of the boundary between the included and excluded parts must be the same. If the excluded portion of the building was a refrigerated warehouse and the included portion was an office, this condition would not be met, because there would be significant energy flows between them.
4. If the included and excluded parts of the building share the same utility meter, and if there is a declining block or similar utility rate used for the analysis, then the energy cost analysis must be based on the full energy use block for the building plus addition. This may be done either by modeling both the existing portion of the building plus the addition served by the utility meter, or by making an appropriate adjustment in the energy cost calculation to account for the difference.

Choosing Space Use Classifications (Table 11.3.1-3)

A key task in modeling the proposed design is assigning space use classifications to different areas of the building. These classifications are used to assign lighting power budget assumptions and to differentiate areas within the building that may have different operating schedules and characteristics (thermostat settings, ventilation rates, etc.).

The choice of space use classifications is taken from one of the two lighting tables in the Standard: either Table 9.5.1 (the building area method) or Table 9.6.1 (the space-by-space method). The designer may choose either classification scheme but may not mix the schemes by using one for part of the building and the other for the rest of the building. "Building," in this context, refers to the space encompassed by a single building permit application, which may be less than the complete building (e.g., a permit for tenant improvements on one floor of a multi-story building).

The designer's choice of space use classification determines how the budget building design lighting power densities will be calculated. The reasons for choosing one method over the other are discussed more fully in Chapter 9 of this Manual.

If the building area method is used for a mixed-use facility, the building may be subdivided into the different areas that correspond to the building types listed in Table 9.5.1. The secondary support areas associated with each of these major building types would be included in each building type. For example, if a building included both office and retail areas, the corridors and restrooms associated with the office occupancy would be included in the office area, and the storage and dressing room areas associated with the sales floor would be included in the retail area.

Schedules (Table 11.3.1-4)

The operating and occupancy schedules for the building and its systems have a large impact on the overall energy cost. The Standard allows designers, with the approval of the authority having jurisdiction, to select reasonable or typical schedules for the building. In selecting the schedules, it is prudent to consider the likely long-term operation of the building. For example, if a new school will initially operate on a traditional schedule, but the school district has a policy of shifting its schools over to year-round operation, then it would be prudent to apply a year-round schedule in the ECB method modeling. The selected schedules should likewise not intentionally misrepresent the operation of the building. If a grocery store chain keeps its stores open 24 hours a day, it would be inappropriate to use a 12-hour-a-day operating schedule in the modeling. The designers are required to specify weekday, Saturday, Sunday, and holiday schedules for each of the following (§ 11.2.1.1b):

- Occupancy;
- Lighting power;
- Miscellaneous equipment power (plug loads);
- Thermostat setpoints;
- HVAC system operation, including system availability, fans, off-hour operation, etc;
- Any other significant loads or equipment that could affect trade-off calculations.

In all cases, the schedules for the proposed design and the budget building design shall be identical. This means that

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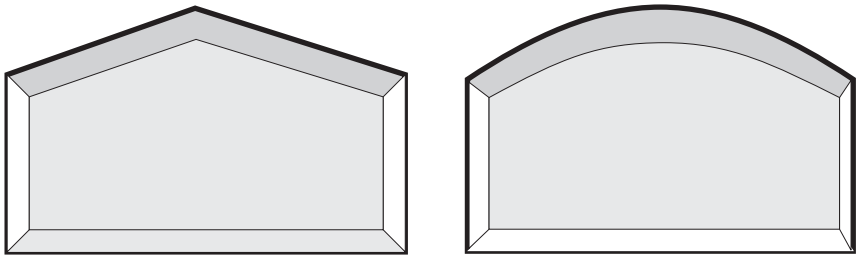

Figure 11-C—Simplifying Building Geometry for Energy Simulation

the proposed building may not take trade-off credit for scheduling changes. It further means that any equipment in the proposed design that saves energy by altering operating patterns or profiles must be modeled explicitly; it is not sufficient simply to assume a schedule change and use that to account for the savings. An example is daylighting controls, which reduce lighting power when daylight is available in a space. The proposed design model must simulate the actual performance of the daylighting control in response to daylight availability, rather than the analyst simply assuming some schedule change that arbitrarily reduces lighting power during daylight hours. Another example of equipment that could not be modeled by reducing operating hours in the proposed design would be occupancy-sensing controls that turn off equipment when not needed. While this type of equipment might well be installed because of the owner's conviction that it is a good investment, there is no credit for it under the ECB method.

Building Envelope (Table 11.3.1-5)

Proposed Design (Table 11.3.1-5a)
The basic rule for modeling the building envelope in the design energy cost calculations is to use the design shown on the final architectural drawings, including building shape, dimensions, surface orientations, opaque construction assemblies, glazing assemblies, etc. In some cases, the building envelope may already exist, as in the case of newly conditioned space or a tenant build-out of a shell building; in these cases, the existing building envelope is modeled.

Any simulation program necessarily relies on a somewhat simplified description of the building envelope. It is usually too time consuming and difficult to explicitly detail every minor variation in the envelope design, and if good engineering judgment is applied, these simplifications won't result in a significant decline in accuracy. The Standard provides three exceptions where more substantial simplifications may be made:

1. *Minor Assemblies*: Frequently, there will be small areas on the building envelope with unique thermal characteristics. The Standard exempts any envelope assembly that covers less than 5% of the total area of a given assembly type (e.g., exterior walls or roofs) from being treated as a separate envelope component. Instead, that area may be added to an adjacent assembly of the same type. For example, if there is an exterior wall constructed of load-bearing masonry, but there are small wood-framed infill areas, the infill areas may be treated as if the entire wall is of masonry. Note that the gross wall area is unchanged, and no areas are left out of the model. Note also that the neglected infill areas are replaced with a wall surface of the same orientation and space adjacency as the assembly. Despite this allowance, it is still preferable and more accurate to model these minor assemblies.
2. *Different Tilt or Azimuth*: This exception, primarily intended to address curved surfaces, specifies the minimum number of orientations into which these surfaces must be split up. The Standard allows similarly oriented surfaces to be grouped under a single tilt or azimuth, provided they are of similar construction and provided the tilt or azimuth of the surfaces are within 45° of each other. They may be grouped as a single surface or a multiplier may be used. The complex curved building plan shown in Figure 11-C (left side) may be replaced with the much simpler pentagonal plan (right side) with little loss in building simulation accuracy.
3. *Reflective Roofs*: By default, exterior roof surfaces, other than those with ventilated attics, must be modeled assuming a surface reflectance value of 0.30. When a proposed design calls for a reflective roof surface, however, the model may assume a long-term average reflectance of 0.45, which credits the lower heat absorption of the reflective surface and makes a conservative

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allowance for degradation of the reflectivity over its lifetime. In order to qualify for this credit, the reflectance of the proposed design roof must exceed 0.70, and its emittance must exceed 0.75. Further, the reflectance and emittance values must be based on tests done in accordance with the ASTM test standards called for in the exception to § 5.5.3.1 in the Standard.

4. *Fenestration*: Interior and/or exterior shading devices in the proposed design shall not be modeled unless they are automatically controlled. In the budget building, shades of any kind are not modeled. When the window area in the design building exceeds the prescriptive maximum, the window area in the budget building is set to the prescriptive maximum area and representative opaque wall area replaces any excess window area. Thus the overall wall area (opaque wall + window area) is the same for both budget and design buildings. The budget building window area is decreased uniformly in each orientation so that the fraction of total window area in each direction is the same in both budget and design buildings.

Budget Building (Table 11.3.1-5b)

The budget building design has the same physical shape characteristics as the proposed design, including:

- Same conditioned floor area;
- Same roof, wall, glazing (up to the maximum allowable window-to-wall-ratio [WWR]), and other surface areas;
- Same surface tilts and orientations.

For the ECB calculations, the characteristics of these envelope components are set to the prescriptive values specified in § 5.5 of the Standard. A few exceptions to these basic rules are described in the following subsections.

Example 11-A—Budget Building Model, Building Envelope

Q

A proposed office building in New York City (climate zone 4A) has a gross wall area of 400,000-ft², and a 60% window-to-wall ratio (see wall and window characteristics in the table below). This window area is greater than the amount allowed by the Standard's Prescriptive Requirements. How is the budget building modeled?

A

Window area in the budget building is reduced to 160,000 ft², which is 40% of the gross wall area. The opaque wall area is increased to 240,000 ft² to maintain the same gross wall area as the proposed design. See the table below.

Proposed Building		Budget Building Envelope Properties	
Total wall area	400,000 ft²	400,000 ft²	
WWR	60%	40%	Maximum WWR
Window area	240,000 ft²	160,000 ft²	
Window frame type	Metal (other)	Metal (other)	U = 0.46 Btu/h·ft²·°F
			SHGC = 0.40
Opaque wall area	160,000 ft²	240,000 ft²	
Wall type	Steel frame	Steel frame	U= 0.064 Btu/h·ft²·°F

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Opaque Assemblies
These are modeled with the minimum U-factors required in § 5.5 for each assembly (mass, wood-framed, etc.). The heat capacities for each assembly type must match the heat capacities of the proposed design. This is because heat capacities may have a significant effect on the performance of envelope components, which shows up in the simulation runs but they are not a requirement of the Standard. Heat capacity is modeled the same in both the budget and proposed runs, and so is energy neutral under the ECB method.

Roof Albedo
The reflectivity of roof surfaces affects solar heat gains and cooling loads. The ECB method allows credit for high reflectivity roof surfaces, provided they meet the requirements discussed above for roofs in the proposed design, by requiring the budget building design reflectivity to be set at 0.3 for all roofs.

Fenestration

- *Overhangs and Other Shading Projections*: The budget building design is assumed to have glazing that is flush with its wall or roof surface. This means that the ECB method gives shading credit for window recesses, overhangs, side fins, or other permanent shading devices that reduce solar gains through the glazing. Interior shading devices, such as miniblinds or curtains, are not permanent and the ECB Method does not provide instructions for how they are to be modeled. Interior shading may be included in the ECB Method but must be modeled identically for both the proposed and budget runs so that they are energy neutral for trade-off purposes (Table 11.3.1-1b).
- *Fenestration Area*: Section 5.5.4.2.1 and 5.5.4.2.2 set the prescriptive upper limits on vertical fenestration area and skylight area. If the proposed design areas are less than those limits, the budget building shall have the same areas and orientations as the proposed design. If the proposed design areas exceed those limits, then the corresponding areas in the budget building design must be adjusted down to the limits (see Example 11-A) and corresponding increases made to opaque areas so that the gross wall area and gross roof area are the same for both the proposed design and the budget building. While the prescriptive envelope requirements provide an exception for street-level, street-side vertical fenestration (e.g., store display windows), the ECB method does not. This exception requires that such fenestration be modeled identically between the proposed and budget runs so that the fenestration is energy neutral in the ECB trade-offs. This means, for example, that one could not claim the maximum credit for display windows, then choose not to install the full allowance of windows and claim a credit.
- *U-Factors*: The budget building design's fenestration U-factor is set to the minimum required for the climate, as specified in Table 5.3 of the Standard. (See Example 11-A.) The minimum U-factor for windows is a function of the framing type used in the proposed design. The U-factor for skylights depends on the skylight type and the area of the skylight, expressed as a ration of skylight area to roof area.
- *SHGC*: The budget building design's fenestration solar heat gain coefficient is set to the value specified for the climate and space category, as specified in Table 5.3-1 through Table 5.3-8 of the Standard (see Example 11-A).

Lighting Systems (Table 11.3.1-6)

Proposed Design (Table 11.3.1-6a)
Under the ECB method, lighting systems are a very important part of overall building performance for most nonresidential building types. The ECB Method builds upon the prescriptive lighting path in § 9.2. Trade-offs between exterior lighting and building energy systems are not permitted. Theatrical and other specialized lighting are exempt from the Standard but generate internal gains nonetheless. This exempt lighting should be modeled in both the proposed and budget designs in addition to the non-exempt lighting. As with HVAC and service hot-water systems, under the ECB Method of calculating the design energy cost, the lighting system power is modeled as shown on the design documents. If a lighting system already exists, then the proposed design is based on actual lighting power of the existing system. If a lighting system has been designed, lighting power shall be determined in accordance with 9.1.3 and 9.1.4.

In the special case where no lighting system or design exists, as in a shell building where the lighting will be installed by a future tenant, then a default lighting power must be assumed, based on the Building Area Method for the appropriate building type. If no building type is known, then an office building is assumed.

Budget Building (Table 11.3.1-6b)
Under the ECB method, lighting system performance is modeled based on lighting power density (LPD). The LPD for the budget building design is determined using one of the two methods defined in § 9.5 (whole building method) or § 9.6 (space-by-space method). Either the building area or space-by-space method may be used,

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but the categorization of spaces must be identical between the budget and proposed designs. The LPD for the proposed design is taken from the design documents for the building. The LPD specified in the models must correspond to the spaces within each thermal block.

Any lighting system efficiency improvements or reductions are reflected as credits or debits in the ECB method trade-off procedures. For example, the owner may decide to invest in a more efficient lighting system in order to provide larger glazing areas, higher SHGCs or higher U-factors in the building envelope, or to avoid the expense of economizer cooling.

Exempt lighting that is not included as part of the interior lighting power budget shall be modeled, if it affects thermal loads within the building, but shall be the same for both the proposed design and the budget building.

Exterior lighting is not included in the ECB method calculations. Those lighting systems must meet the Standard's prescriptive requirement.

Under the Standard, required lighting controls (primarily automatic shutoff controls) are modeled using the lighting schedules, which must be identical for the budget and proposed runs. Daylighting controls are not modeled in the budget building model but may be modeled in the proposed design model. If there are any areas of the building for which the lighting systems are not defined, then those areas are modeled using base LPDs for both the proposed and budget runs (based on the building area method), and their lighting systems are energy neutral for the ECB calculations.

Thermal Blocks—HVAC Zones Designed (Table 11.3.1-7)

The ECB method distinguishes between HVAC zones and thermal blocks. An HVAC zone is physically determined by the design of the HVAC system. It includes some number of thermodynamically similar spaces whose loads can be satisfied through use of a single thermostat (or other type of temperature control). The duct outlets or other terminal units controlled by a single thermostat serve the zone.

A thermal block is a simulation program term. It is similar to an HVAC zone, except that often in simulation practice a number of zones, which are similar in loads and are served by similar systems, are combined into a single thermal block for modeling purposes. Obviously, this requires engineering judgment to avoid modeling error, but it can be done reasonably.

For example, the interior HVAC zones of a multi-story building may be physically separate zones on each floor, but they may often reasonably be combined into a single thermal block in the simulation model of the building because they have similar loads and are served by similar systems. However, a cafeteria or computer room in an office building would need to be modeled separately, as would lower-floor retail uses.

The basic rule of the ECB method is that thermal blocks must be defined identically for the budget building design and the proposed design (Table 11.3.1-7a). This is consistent with the rule that the shape and area of the building envelope for the budget building design be the same as for the proposed design, that the space use classifications be the same, and so forth. Furthermore, each HVAC zone, as defined on the design drawings, must be modeled as a separate thermal block (Table 11.3.1-7a). Zones may be combined, or multipliers may be used, if *all* the following conditions are met:

1. All of the space use classifications must be the same throughout the thermal block. This ensures that they have the same load and schedule characteristics.
2. For exterior HVAC zones with glazing, the glazing for all zones included in the thermal block must have the same orientation, or at least their orientations must be within 45 degrees of each other. This ensures that they have the same solar heat gain characteristics. This is not to say that the zones may not have two or more glazing orientations—a corner office could easily have two—but that the zones must have similar orientations. It would be acceptable, for example, to group all of the northeast corner offices on the intermediate floors of an office tower into a single thermal block.
3. All of the HVAC zones in the thermal block must be served either by the same HVAC system or by the same kind of HVAC system. This is so that the simulation program can accurately model the performance of the system(s) serving the block.

Thermal Blocks—HVAC Zones Not Designed (Table 11.3.1-8)

When HVAC zones are not designed at the time of the permit application for which the ECB method is being used, then the configuration of the thermal blocks must be assumed (Table 11.3.1-8a). This situation is quite common in commercial buildings where the future tenants will determine the zoning of spaces in the building. In this case, thermal blocks must be defined based on similar internal load densities, occupancy, lighting, thermal and space temperature schedules, etc. The Standard provides several guidelines.

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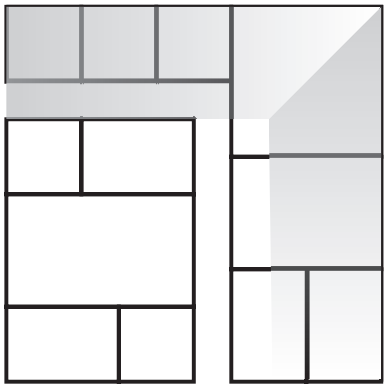

Figure 11-D—Thermal Zoning in Building Simulation When the HVAC Zones Are Not Yet Designed

Separate Orientations with Glazing
Glazed exterior walls should be assigned to different perimeter thermal blocks for each major orientation. Orientations within 45 degrees of each other may be combined. Spaces with two or more glazed orientations, such as corner offices, should be divided proportionately between zones having the different orientations. Figure 11-D shows a strategy for allocating corners to two different thermal blocks. Remember that this allocation is not necessary when the thermal zoning of the HVAC system has already been designed.

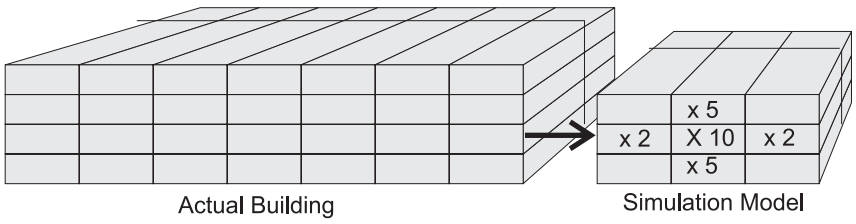

Figure 11-E—Thermal Blocks for Apartment Building

Separate Interior and Perimeter Spaces
When the HVAC zones are not yet designed, assign separate thermal blocks to interior spaces located more than 15 feet from an exterior wall and to perimeter spaces within 15 feet of the exterior (see Example 11-B). If the HVAC zones are designed, apply a thermal block to each HVAC zone.

Separate Top, Bottom, and Middle Floors
Spaces exposed to ambient conditions, such as the top floor or an overhanging floor, and spaces in contact with the ground, such as the ground floor, must be zoned separately from zones that are not exposed to ambient conditions, such as intermediate floors in a multi-story building.

Thermal Blocks—Multifamily Residential Buildings (Table 11.3.1-9)

Multifamily residential buildings are another special case (Table 11.3.1-9a). In general, the residential spaces must be treated as separate thermal blocks, except that some combinations are allowed. Units all facing the same orientation, and having similar conditions at the top, bottom, and sides, may be combined. Similar corner units may be combined, and units with similar roof or floor loads may be combined (see Figure 11-E).

HVAC Systems (Table 11.3.1-10)

Proposed Design (Table 11.3.1-10a)

Because of the scope restrictions on the ECB method discussed at the beginning of this chapter, there will always be an HVAC system in an ECB model. The basic rule for modeling HVAC systems to find the design energy cost is to base the model as completely as possible on the actual system design as shown in the construction documents. This includes the system type, equipment capacities and efficiencies, controls, ancillary features (such as economizers), etc. The equipment efficiencies may need to be adjusted to meet the needs of the simulation program. While efficiencies may be most accurately specified at the building's design conditions, most simulation programs require efficiencies to be specified at standard rating conditions, such as those given in § 6.4.1.1 of the Standard. If that is the case, than the efficiency values needed by the simulation program should be used in the modeling.

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Some special cases related to HVAC systems need to be considered:

1. *Complete HVAC System Exists*: An example might be an existing speculative building that is being built out for a tenant. The subject of the building permit is primarily the interior construction and lighting system and does not include the HVAC system because it had already been built and permitted. In a case like this, the design and budget energy cost models are based on the existing HVAC system. It would also include the existing building envelope, plus the new lighting system and any other new energy features.

2. *No Heating System Exists*: If no heating system exists, a default heating system must be assumed and modeled. It should be a simple, fossil-fueled heating system with sufficient capacity to meet the design heating loads for the building. An identical system (with sizing adjustments) must be assumed for the budget building design (See § 11.3.2j).

4. *No Cooling System Exists*: If no cooling system exists, a default cooling system must be assumed and modeled. It should consist of one air-cooled single-zone system for each thermal block (a thermal block is a collection of one or more HVAC zones grouped together for simulation purposes; spaces need not be contiguous to be combined within a single thermal block). This identical system (with sizing adjustments) must be assumed for the budget building design.

Budget Building (§ 11.3.2-10b)

Because of the large number of variations in HVAC system types and equipment selections, the rules for the budget building design HVAC system selection and specification are complex. Before describing the many exceptions and special considerations; however, some general observations are provided below.

The HVAC system in the budget building design just meets the prescriptive requirements of the Standard. There are many ways for the proposed design system

Table 11-A—Number of Chillers

(This is Table 11.3.2B in the Standard)

Total Chiller Plant Capacity	Number of Chillers
≤ 300 tons (≤ 1055 kW)	1
> 300 tons, < 600 tons (> 1055 kW, < 2110 kW)	2 sized equally
≥ 600 tons (≥ 2110 kW)	2 minimum with chillers added so that no chiller is larger than 800 tons (2813 kW), all sized equally

Table 11-B—Water Chiller Types

(This is Table 11.3.2C in the Standard)

Individual Chiller Plant Capacity	Electric Chiller Type	Fossil Fuel Chiller Type
≤ 100 tons (≤ 352 kW)	Reciprocating	Single-effect absorption, direct fired
> 100 tons, < 300 tons (> 352 kW, < 1055 kW)	Screw	Double-effect absorption, direct fired
≥ 300 tons (≥ 1055 kW)	Centrifugal	Double-effect absorption, direct fired

Example 11-B—Applying Thermal Zones Before Duct Design Completion

Q

A permit has been applied for before the duct design has been completed. The interior partition walls are 25 ft from the exterior walls. How would the design and budget building thermal zones be applied?

A

As described in Table 11.3.1-8b, when the HVAC zones have yet to be designed, the perimeter thermal zones in the simulation will extend inward 15 ft from the perimeter wall regardless of partitions or interior walls. Figure 11-D illustrates how the thermal zones and architectural zoning of the building differ.

Note that this 15 ft rule only applies to HVAC systems that have yet to be designed. When the HVAC zoning has been designed, the thermal zones in both the proposed design and budget buildings should reflect the actual zoning.

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to exceed the energy performance of this budget system, which would generate trade-off credits; likewise, there are ways for it perform less efficiently, which would result in trade-off debits that must be compensated with better performance of other system components.

The ECB method does not provide credit for changing the HVAC system type. Instead, it presumes that the system type is a given and that any trade-offs are made between more or less efficient versions of the chosen system. This was done for consistency with the rest of the Standard and to prevent gamesmanship in modeling the hypothetical HVAC system of the budget building design. The details of the budget system are defined by the Standard, and are based on the proposed design system characteristics. The budget systems are deemed representative of current standard practice that meets the Standard.

In situations where the entire HVAC system design is not known, as in the case of a core and shell design, the unknown parts of the system are assumed to meet the prescriptive requirements and to be energy neutral. Again, this prevents gamesmanship with the undefined system components.

Gamesmanship, in the sense of this discussion, is the practice of artificially reducing the efficiency of the budget building design in order to increase the apparent relative efficiency of the proposed design, thus generating an undeserved trade-off credit. Such an undeserved credit could be used to reduce the efficiency of other system components, and the result could be a building that does not meet the minimum efficiency level established for the building by the Standard. The ECB method is more vulnerable to this sort of abuse, which is why the rules for constructing the budget building design must be so specific.

The ECB modeling rules for part-load efficiency and system sizing are intended to minimize these effects on the trade-off calculations for the other measures in the building. For example, credits are not generated for a difference between a properly sized proposed design system and an improperly sized budget building design system. The modeling rules are discussed individually in the following sections.

Limited Trade-Offs (§ 11.3.2a)
The ECB method does not allow unrestricted trade-offs for every type of efficiency measure that a designer might propose. Only those trade-offs specifically allowed may be claimed. This restriction takes the form of a modeling rule stating that any components or parameters not specifically addressed by the Standard must be modeled identically between the proposed design and the budget building design. In other words, any measures not specifically allowed are kept energy neutral in the ECB trade-offs. For HVAC systems, the rules for the budget building design in § 11.3.2 list the parameters and components that may be included in trade-off calculations. This extends to any components for which there are specific minimum efficiency requirements (specified in § 6.4 and 6.5, the HVAC mandatory and prescriptive requirements, respectively). For those components, the minimum efficiency levels are modeled in the budget building design; actual efficiencies are modeled in the proposed design. Note that most of the Mandatory Provisions specify minimum efficiency levels that must be met even when the ECB Method is used (see § 11.1.4).

Minimum Efficiencies (§ 11.3.2b)
The minimum efficiencies for HVAC equipment (§ 6.4) and for service hot-water heating equipment (§ 7.4) must be used for the applicable equipment in the budget building design. This includes any part-load efficiencies if these are specified. These efficiency requirements set the baseline for equipment trade-offs under the ECB method. The actual equipment efficiency of the proposed design is then used to calculate the energy cost budget. Since mechanical and service hot-water heating equipment efficiency is a mandatory requirement, if the equipment is covered by these equipment requirements, the equipment efficiency in the proposed design must be equal to or greater than the prescriptive equipment efficiency. If mechanical or service hot-water heating equipment falls outside of those listed in the efficiency tables, the budget equipment efficiency shall be equal to the efficiency of the equipment in the proposed design. Thus the only trade-off available for equipment efficiency is to specify higher efficiencies than those called for in the Standard, which would generate credit in the energy cost for the design.

Fan Energy (§ 11.3.2c)
Many types of HVAC equipment have overall efficiency ratings that include the supply fan power. A good example is the energy efficiency ratio (*EER*), which compares the net cooling effect in Btu/h to the total input power of the packaged system in watts to drive the supply and condenser fans and the refrigerant compressor (see Equation 11-A). Note that the difference between gross cooling and net cooling is the heat addition from the supply fan.

When the HVAC system performance is defined in terms of an overall figure like *EER*, it is necessary for the simulation

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models of both the proposed and budget designs to separate supply fan energy from cooling system energy. The compressor and the fans would also be controlled differently, so their operating profiles must reflect their actual operation. This improves the accuracy of the simulation, since the energy needed to deliver conditioned air into spaces in the building relies on different physical principles than the energy needed for cooling.

The manufacturers of HVAC equipment publish a variety of sizing parameters that can assist in calculating the coefficient of performance (*COP*), the ratio of cooling energy provided per unit of energy input into the cooling section (compressor and condenser) of packaged HVAC equipment. The performance of this cooling section is a function of supply airflow rate, outside dry-bulb temperature, and the wet-bulb and dry-bulb temperature of air entering the cooling coil. In general, simulation programs require the rated energy consumption of the equipment at ARI (Air-Conditioning and Refrigeration Institute) standard test conditions: 95°F outdoor dry-bulb temperature and 80°F dry-bulb, 67°F wet-bulb temperature of air entering the coil. The simulation program will use an overall coefficient of performance (*COP*) for the cooling section of packaged HVAC equipment (see Equation 11-B).

If the supply fan watts at ARI conditions are available, the *COP* can also be expressed as Equation 11-C.

Example 11-C illustrates the process of calculating a *COP* for the compressor and the condenser. Note, however, that this *COP* by itself does not yield the energy consumption of the cooling section of packaged HVAC systems; it is used in conjunction with other variables, such as the load placed upon the system, ambient air temperature, and the psychrometric

Example 11-C—Calculating *COP* for Compressor and Condenser

Q

A 15-ton packaged rooftop single-zone system having an *EER* of 8.6 (*COP* of 2.5) is specified for a building. The following table gives the design specifications. How should this be modeled?

Equipment parameter	Value
Net Cooling Capacity (Btu/h)	174,000
Total Packaged Unit Input Power (W)	20,128
EER	8.64
Gross Cooling Cap (ARI conditions)	182,000

A

The supply fan power is the difference between the gross and the net cooling capacity.

$$\text{Supply Fan Power} = \frac{(182{,}000 - 174{,}000)[\text{Btu/h}]}{3.413[\text{Btu/W}\cdot\text{h}]} = 2343\ \text{W}$$

From the equation for cooling system *COP*, the cooling provided by the compressor and the condenser into the airstream in Btu/h per Btu/h of electrical power input is:

$$\text{COP} = \frac{182{,}000\ [\text{Btu/h}]}{(20{,}128 - 2343\ \text{W}) \times (3.413\ \text{Btu/W}\cdot\text{h})} = 3.0$$

Some simulation programs use an energy input ratio (*EIR*), which is 1/*COP*. In this case, the *EIR* for this piece of equipment would be 1/3 or 0.333.

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properties of the air entering the cooling coil.

Many larger systems have return or relief fans that work together with the supply fans. If the systems are variable volume, they must be modeled as operating whenever the spaces they serve are occupied. Constant volume fan systems can be cycled on and off to meet thermal loads; however, the same control strategy needs to be used in both the design and budget building designs.

Air Economizers (§ 11.3.2e)
HVAC system types that have air distribution systems (system types 1–4 and 8–11 in Table 11-A) must be modeled with an air economizer in the budget building design. These system types cover everything except two-pipe and four-pipe fan coils and water-source heat pumps. The economizer design must meet all the requirements for air economizers specified in § 6.5.1 and § 6.5.1.1, including the design capacity and the requirement for operating in sequence with the mechanical cooling equipment. The economizer must be modeled with a high-limit dry-bulb temperature shutoff. The shutoff temperatures are specified in the Standard in Table 6.5.1.1.3B for fixed dry-bulb controllers.

Water Economizers (§ 11.3.2e)
HVAC system types that have water distribution systems (system types 5–7 in Table 11-A must be modeled with a water economizer in the budget building design. These system types include two-pipe and four-pipe fan coils and water-source heat pumps. The economizer design must meet all the requirements for water economizers specified in § 6.5.1 and § 6.5.1.2, including the design capacity and the integrated economizer control. The economizer must be modeled with a high-limit dry-bulb temperature shutoff. The shutoff temperatures are specified in the Standard in Table 6.5.1.1.3B for fixed dry-bulb controllers.

Preheat Coils (§ 11.3.2f)
As the Standard succinctly states, "If the proposed design system has a preheat coil, the budget building design's system shall be modeled with a preheat coil controlled in the same manner." In other words, this is not a trade-off measure.

Design Supply Air Rates (§ 11.3.2g)
The supply air quantities in a system can have a significant effect on the energy cost budget. The Standard allows designers considerable latitude to design the supply air system more efficiently than base efficiency. The supply air quantity modeled for the budget building design must be based on a supply-air-to-room-air temperature difference of 20°F (11°C). If return or relief fans are specified in the proposed design, the budget building design shall also be modeled with the same fan-type sized for the budget system's supply fan air quantity less the minimum outdoor air, or 90% of the supply fan air quantity, whichever is larger.

Fan System Efficiency (§ 11.3.2h)
Fan system efficiency is a very important factor in overall building energy consumption, yet it is difficult to establish overall system efficiency requirements for all cases. Consequently, the requirements in § 6.5.3.1 only tend to address the worst cases. Using these criteria would not reflect typical practice. In general, the ECB method requires that the fan system efficiency be the same for the budget building as it is for the proposed building.

Equipment Sizing (§ 11.3.2i and 11.3.2j)
The sizing of equipment can have a significant impact on system efficiency, depending on how efficient the equipment is at part load and how often it operates at part load. The ECB method rules are designed to prevent sizing differences

$$EER = \frac{\text{Net Cooling}[\text{Btu}/\text{h}]}{\text{Total Input Power}[\text{W}]} = \frac{(\text{Gross Cooling} - \text{Supply Fan Power})[\text{Btu}/\text{h}]}{\text{Total Input Power}[\text{W}]} \quad (11\text{-B})$$

$$COP = \frac{\text{Total Cooling Capacity } [\text{Btu}/\text{h}]}{(\text{Compressor W} + \text{Condenser Fan W}) \times (3.413 \text{ Btu}/\text{W}-\text{h})} \quad (11\text{-C})$$

$$COP = \frac{\text{Total Cooling Capacity } [\text{Btu}/\text{h}]}{(\text{Total Unit W} - \text{Supply Fan W}) \times (3.413 \text{ Btu}/\text{W}-\text{h})} \quad (11\text{-D})$$

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between the proposed design and the budget building design from influencing trade-offs. For example, if the proposed design was sized to have good part-load performance and the budget building design was sized to have poor part-load performance, then the system would be given a credit for this difference. This would not be a real savings, however, because the sizing of the budget building design is arbitrary. To avoid this type of problem, the ECB Method requires a multiple-step sizing procedure:

- First, a sizing run must be done for the proposed design. This determines the "ideal" equipment sizing.
- Next, the sizing ratios between the actual equipment capacities of the proposed design and the sizing run capacities are determined for each system component (chiller, supply fans, etc.).
- Then a sizing run is done for the budget building design as specified in the Standard to determine the "ideal" equipment sizing for the budget design.
- Finally, the equipment capacities in the budget building design are adjusted so they have the same sizing ratios as were calculated for the proposed design.

This sequence of calculations depends, of course, on the simulation program having the capability to do sizing calculations, which is a required capability (§ 11.2.1.3).

As a final check that these adjustments were done correctly and that the two runs have comparable sizing characteristics, the unmet load hours reported by the simulation program for both runs may not differ by more than 50 hours per year. Note that this requirement does not specify how many total unmet hours are allowed; this number can be affected by many simulation program assumptions and algorithms. The requirement only specifies the degree to which the two runs may disagree with each other on unmet load conditions.

This equipment sizing requirement prevents the energy cost budget run from being based on an unfairly oversized budget design system that is operating at poor part-load efficiency while the more appropriately sized proposed design system is operating closer to its optimal efficiency. This requirement helps ensure a fair comparison based upon building performance rather than upon arbitrary sizing or different comfort conditions represented by the number of hours that loads are not met.

HVAC Systems Mapping (§ 11.3.2j)

The heart of the ECB rules for the budget building design's HVAC system is the HVAC Systems Map, shown in Figure 11-F. This diagram shows the type of system required to be defined for each HVAC system in the budget building design, based on the characteristics of the system in the proposed design. The map is supported by a table of detailed specifications for each of the numbered systems (see Table 11-A). To use the HVAC Systems Map, follow these steps (§ 11.3.2k) for each HVAC system:

1. *Determine the Condenser Cooling Source*: The condenser cooling source for the cooling system in the proposed design must be determined. There are two choices: air-cooled condensers, and water- or ground-cooled condensers (including evaporatively cooled). If there is no mechanical cooling system, or if the proposed design does not require heat rejection, then the Air/None choice applies. Closed circuit dry-coolers are considered air-cooled. Systems utilizing district cooling are considered water-cooled.

2. *Determine the Heating System Classification:* The classification of the heating system of the proposed design must be determined. The choices are Electric Resistance, Heat Pump (including air-source and water-source), or Fossil Fuel (gas, fuel oil, propane, etc.). If the heat source is a district heating system (steam or hot water), or if there is no heat source, then the choice would be Fossil Fuel. There is a special case for mixed heating system types, discussed on next page.

3. *Determine the Budget Building Design System Type Category*: This is based on the proposed design system type. If the occupancy is residential (including hotel/motel guest rooms) and it is a single-zone system, then select "Single-Zone Residential System." If the occupancy is not residential, but it is a single-zone system, then select "Single-Zone Nonresidential System." For any other type of system, select "All Other." A single-zone system uses one space temperature control device, such as a thermostat, for the entire system. If there is more than one space temperature control device on the system, then the "All Other" category applies.

4. *Find System Type*: After making the previous three choices, follow the paths in the HVAC Systems Map to find the type of system for the budget building design. For example, a building with a chiller and cooling tower, using an electric-fired boiler and a central variable air volume system would use System 1 (Condenser Cooling Source = Water; Heating System Classification = Electric Res; System Type = All Other).

If the proposed building system is a ground source heat pump (geo-exchange system), then the budget system shall be system 6 (water-source heat pump).

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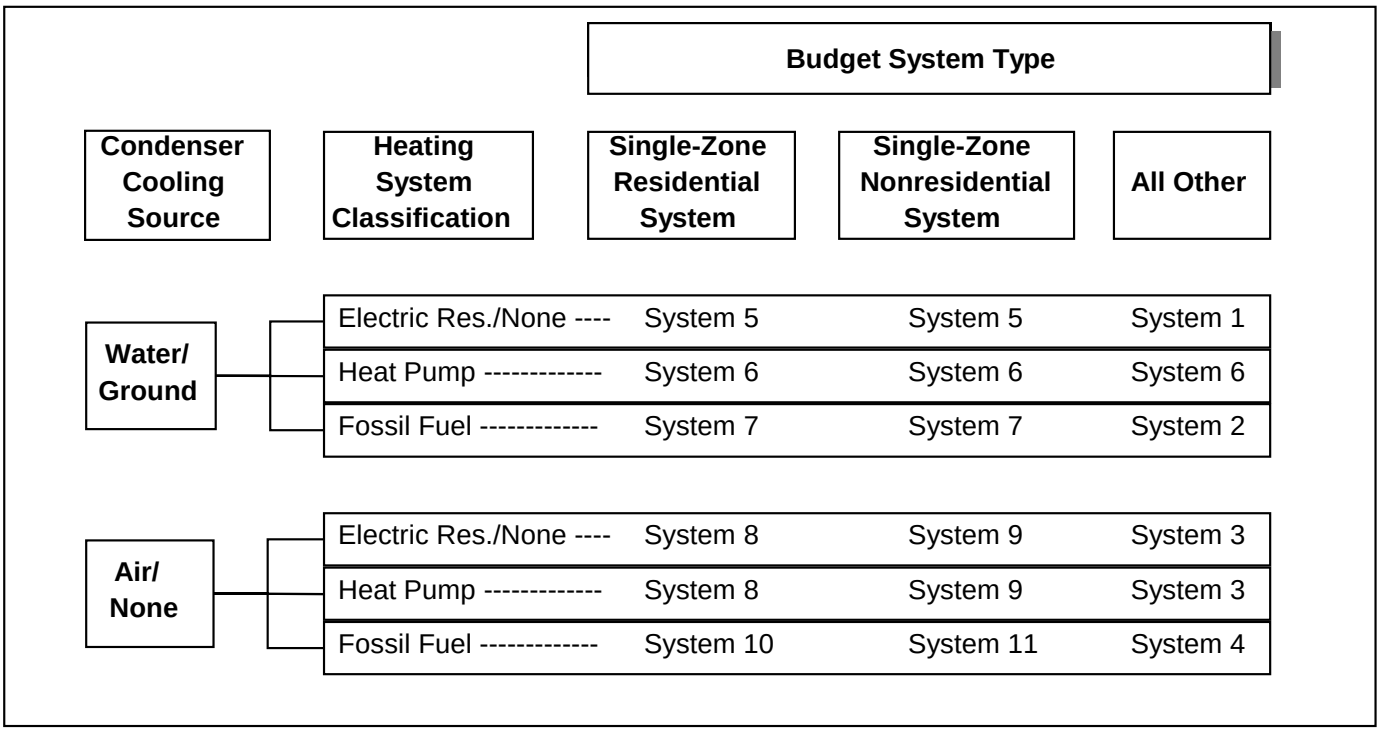
Budget System Type
Condenser Cooling Source
Heating System Classification
Single-Zone Residential System
Single-Zone Nonresidential System
All Other
Water/ Ground
Electric Res./None ---- System 5 System 5 System 1
Heat Pump ---------- System 6 System 6 System 6
Fossil Fuel ---------- System 7 System 7 System 2
Air/ None
Electric Res./None ---- System 8 System 9 System 3
Heat Pump ---------- System 8 System 9 System 3
Fossil Fuel ---------- System 10 System 11 System 4

Figure 11-F—HVAC Systems Map

(This is Figure 11.3.2 in the Standard)

After finding the Budget System Type, turn to Table 11-A for more specifics about the type of system, its fan control, cooling type, and heating type. The table is supplemented by an extensive set of notes.

The special case mentioned in item 2 above is a mixed fuel heating system. An example might be a proposed design with a perimeter hydronic heating system fired by a natural gas boiler, supplemented by electric resistance reheat strips in some of the air handlers. The first step is to determine which heating type is primary and which is secondary, based on the total installed output capacity of each as designed for the spaces served. Note that this could be different from the total capacity of the central source; for example, the sum of the output capacities of the hydronic heating coils could be larger or smaller than the total capacity of the boiler, depending on the system's design and control features. Once the primary heating system type is determined, it is used in the HVAC Systems Map to select the corresponding budget system type. The secondary heating system is modeled identically in the proposed design and the budget building design, except that the minimum allowable equipment efficiency will be used in modeling the budget building design calculations and the actual efficiency will be used for the proposed design calculations.

Service Hot-Water Systems (Table 11.3.1-11)

Proposed Design (Table 11.3.1-11a)

The ECB method provides an opportunity to include the service hot-water systems in the overall building performance, and so for it to be part of the trade-off procedures.

These systems are treated similarly to the HVAC systems discussed above. The basic rule is that the proposed design hot-water system is modeled in accordance with the design documents, including equipment types, capacities, efficiencies, insulation, controls, and all other related performance parameters. In cases where a service hot-water system already exists, the

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model must be based on that system's characteristics. If neither case applies, i.e., there is no service hot-water system, then none is modeled. This last rule is different than for other energy-related systems in the building because service water heating generally has little interaction with the other energy systems.

Budget Building (Table 11.3.1-11b)
Service water-heating systems may participate in the ECB method trade-offs when they are eligible (under the same permit application as the rest of the proposed design). They must be modeled as the same water heater type and must be assumed to have the same performance characteristics, such as hot water demand, fuel type, operating schedules, circulating pumps, etc. The only characteristic, then, that may contribute to trade-off credits is the water heater equipment efficiency.

There is a special case where the service water heater is also used for space heating (or vice versa). In this case, § 7.5 of the Standard governs the system characteristics. For ECB method purposes, the budget building design is assumed to be a separate boiler for space heating and a separate water heater for service hot-water heating, each meeting the minimum efficiency requirements allowed by the Standard (Tables 6.8.1F and 7.8). The equipment should be modeled at an appropriate size to meet the load.

For 24-hour-per-day facilities that meet the prescriptive criteria for use of condenser heat recovery systems described in Section 6.5.6.2, a system meeting the requirements of that section shall be included in the baseline building design regardless of the exceptions to 6.5.6.2. If a condenser heat recovery system meeting the requirements described in Section 6.5.6.2 cannot be modeled, the requirement for including such a system in the actual building shall be met as a prescriptive requirement in accordance
with 6.5.6.2, and no heat-recovery system shall be included in the proposed or budget building designs.

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Table 11-C—Budget System Descriptions

(This is Table 11.3.2A in the Standard)

SYSTEM	SYSTEM TYPE	FAN CONTROL	COOLING TYPE	HEATING TYPE
1	Variable air volume with parallel fan-powered boxes (Note 1)	VAV (Note 4)	Chilled Water (Note 5)	Electric Resistance
2	Variable air volume with reheat (Note 2)	VAV (Note 4)	Chilled Water (Note 5)	Hot Water Fossil Fuel Boiler (Note 6)
3	Packaged variable air volume with parallel fan-powered boxes (Note 1)	VAV (Note 4)	Direct Expansion (Note 3)	Electric Resistance
4	Packaged variable air volume with reheat (Note 2)	VAV (Note 4)	Direct Expansion (Note 3)	Hot Water Fossil Fuel Boiler (Note 6)
5	Two-pipe fan-coil	Constant Volume (Note 9)	Chilled Water (Note 5)	Electric Resistance
6	Water-source heat pump	Constant Volume (Note 9)	Direct Expansion (Note 3)	Electric Heat Pump and boiler (Note 7)
7	Four-pipe fan coil	Constant Volume (Note 9)	Chilled Water (Note 5)	Hot Water Fossil Fuel Boiler (Note 6)
8	Packaged terminal heat pump	Constant Volume (Note 9)	Direct Expansion (Note 3)	Electric Heat Pump (Note 8)
9	Packaged rooftop heat pump	Constant Volume (Note 9)	Direct Expansion (Note 3)	Electric Heat Pump (Note 8)
10	Packaged terminal air conditioner	Constant Volume (Note 9)	Direct Expansion	Hot Water Fossil Fuel Boiler (Note 6)
11	Packaged rooftop air conditioner	Constant Volume (Note 9)	Direct Expansion	Fossil Fuel Furnace

Notes to Table 11-C:

1. Fans in parallel VAV fan-powered boxes shall be sized for 50% of the peak design flow rate and shall be modeled with 0.35 W/cfm (0.74 W per L/s) fan power. Minimum volume setpoints fan-powered shall be equal to the minimum rate for the space required for ventilation consistent with 6.3.2.1 Exception (a) 1. Supply air temperature setpoint shall be constant at the design condition [see 11.4.3 (h)].

2. Minimum volume setpoints for VAV reheat boxes shall be 0.4 cfm/ ft^2 (2.15 L/s $\cdot m^2$) of floor area, or minimum ventilation rate, whichever is larger, consistent with 6.3.3.1, Exception (a) 2. Supply air temperature shall be reset based on zone demand from the design temperature difference to a 10°F (5.6°C) temperature difference under minimum load conditions. Design airflow rates shall be sized for the reset supply air temperature, i.e., a 10°F (5.6°C) temperature difference.

3. The fuel type for the cooling system shall match that of the cooling system in the proposed design.

4. Constant volume can be modeled if the system qualifies for Exception (b) to 6.5.2.1. When the proposed design system has a supply, return, or relief fan motor 25 hp (18.5 kW) or larger, the corresponding fan in the budget building design's VAV system shall be modeled assuming a variable-speed drive. For smaller fans, a forward-curved centrifugal fan with inlet vanes shall be modeled. If the proposed design's system has a direct digital control system at the zone level, static pressure set point reset based on zone requirements in accordance with 6.5.3.2.3 shall be modeled.

5. For systems using purchased chilled water, the chillers are not explicitly modeled and chilled water costs shall be based as determined in 11.2.3. Otherwise, the budget building design's chiller plant shall be modeled with chillers having the number as indicated in Table 11.3.2B as a function of budget building chiller plant load and type as indicated in Table 11.3.2C as a function of individual chiller load. Where chiller fuel source is mixed, the system in the budget building design shall have chillers with the same fuel types and with capacities having the same proportional capacity as the proposed design's chillers for each fuel type. Chilled water supply temperature shall be modeled at 44°F (6.7°C) design supply temperature and 56°F (13°C) return temperature. Piping losses shall not be modeled in either building model. Chilled water supply water temperature shall be reset in accordance with 6.5.3.2. Pump system power for each pumping system shall be the same as the proposed design; if the proposed design has no chilled water pumps, the budget building design pump power shall be 22 W/gpm (349 kW/1,000 L/s) [equal to a pump operating against a 75 foot head, 65% combined impeller and motor efficiency]. The chilled water system shall be modeled as primary-only variable flow with flow maintained at the design rate through each chiller using a bypass. Chilled water pumps shall be modeled as riding the pump curve or with variable-speed drives when required in 6.5.4.1. The heat rejection device shall be an axial fan cooling tower with two-speed fans if required in 6.5.5. Condenser water design supply temperature shall be 85°F (29°C) or 10°F (5.6°C) approach to design wet -bulb temperature, whichever is lower, with a design temperature rise of 10°F (5.6°C). The tower shall be controlled to maintain a 70°F (21°C) leaving water temperature where weather permits, floating up to leaving water temperature at design conditions. Pump system power for each pumping system shall be the same as the proposed design; if the proposed design has no condenser water pumps, the budget building design pump power shall be 19 W/gpm (301 kW/1,000 L/s) [equal to a pump operating against a 60 foot head, 60% combined impeller and motor efficiency]. Each chiller shall be modeled with separate condenser water and chilled water pumps interlocked to operate with the associated chiller.

6. For systems using purchased hot water or steam, the boilers are not explicitly modeled and hot water or steam costs shall be based on actual utility rates. Otherwise, the boiler plant shall use the same fuel as the proposed design and shall be natural draft. The budget building design boiler plant shall be modeled with a single boiler if the budget building design plant load is 600,000 Btu/h (176 kW) and less, and with two equal sized boilers for plant capacities exceeding 600,000 Btu/h (176 kW). Boilers shall be staged as required by the load. Hot water supply temperature shall be modeled at 180°F (82°C) design supply temperature and 130°F (54°C) return temperature. Piping losses shall not be modeled in either building model. Hot water supply water temperature shall be reset in accordance with 6.3.3.2. Pump system power for each pumping system shall be the same as the proposed design; if the proposed design has no hot water pumps, the budget building design pump power shall be 19 W/gpm (301 kW/1,000 L/s) [equal to a pump operating against a 60 foot head, 60% combined impeller and motor efficiency]. The hot water system shall be modeled as primary-only with continuous variable flow. Hot water pumps shall be modeled as riding the pump curve or with variable-speed drives when required by 6.5.4.1.

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Notes to Table 11-C, continued:

7. Water-source heat pumps shall be connected to a common heat pump water loop controlled to maintain temperatures between 60°F (16°C) and 90°F (32°C). Heat rejection from the loop shall be provided by an axial fan closed circuit evaporative fluid cooler with two-speed fans if required in 6.3.5. Heat addition to the loop shall be provided by a boiler that uses the same fuel as the *proposed design* and shall be natural draft. If no boilers exist in the *proposed design*, the budget building boilers shall be fossil fuel. The *budget building design* boiler plant shall be modeled with a single boiler if the *budget building design* plant load is 600,000 Btu/h (176 kW) or less, and with two equally sized boilers for plant capacities exceeding 600,000 Btu/h (176 kW). Boilers shall be staged as required by the load. Piping losses shall not be modeled in either building model. Pump system power shall be the same as the *proposed design*; if the *proposed design* has no pumps, the *budget building design* pump power shall be 22 W/gpm (349 kW/1000L/s), which is equal to a pump operating against a 75 foot (23 m) head, with a 65% combined impeller and motor efficiency. Loop flow shall be variable with flow shut off at each heat pump when its compressor cycles off as required by 6.3.4.4. Loop pumps shall be modeled as riding the pump curve or with variable speed drives when required by 6.3.4.1

8. Electric air-source heat pumps shall be modeled with electric auxiliary heat. The system shall be controlled with a multi-stage space thermostat and an outdoor air thermostat wired to energize auxiliary heat only on the last thermostat stage and when outdoor air temperature is less than 40°F (4°C).

9. Fans shall be controlled in the same manner as in the proposed design, i.e., fan operation whenever the space is occupied or fan operation cycled on calls for heating and cooling. If the fan is modeled as cycling and the fan energy is included in the energy efficiency rating of the equipment, fan energy shall not be modeled explicitly.

Miscellaneous Loads (Table 11.3.1-12)

Proposed Design (Table 11.3.1-12a)
If there are significant energy-related systems, besides those discussed above, that generate internal heat gains or otherwise interact with the other energy systems, then they should be modeled as part of the proposed and budget designs. For example, most nonresidential buildings have substantial plug loads and some have process loads. These should be modeled using the best available information about their energy characteristics from the design drawings or, when applicable, from the existing systems already in place. The authority having jurisdiction, typically the local building official, must approve the assumptions for these other systems as reasonable. Systems that do not interact substantially with other energy systems, such as elevators or parking garage fans, may be neglected in the design energy cost modeling.

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Budget Building (Table 11.3.1-12b)
The ECB method does not allow credit for non-HVAC motors or for other miscellaneous energy-related equipment in a building, such as elevators, conveyors, autoclaves, etc. Where these systems contribute significant loads to the building, they should be modeled, but they must be identical in the proposed and budget runs.

Modeling Exceptions (Table 11.3.1-13)

In general, all the energy systems of the proposed design must be included in calculating the design energy cost (Table 11.3.1-13a). The Standard, however, does have some exceptions that may be applied only in rare, special cases. It is allowable to exclude some components or systems of the proposed design provided they do not affect the energy usage of the other systems being modeled for trade-off purposes. For example, if the service hot-water heating system is not located in the conditioned space, and if it is not generating significant heat gains that affect the HVAC system, then it may be ignored in the model. All systems that are excluded on this basis, however, must still meet the prescriptive requirements that apply to them. This exception can help to simplify the modeling somewhat, but only in ways that will not affect the accuracy of the ECB method trade-off calculations. If the approved utility rate structures vary based on the total energy consumption or peak energy load of the building, and if excluding components would affect the energy cost comparison, then these components must be included in the modeling.

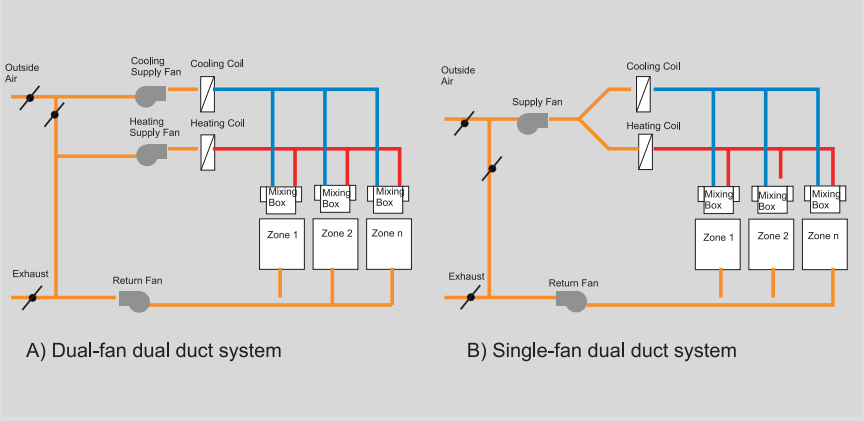
Limitations to the Simulation Program (Table 11.3.1-14)

There may also be cases where the simulation program lacks modeling capabilities needed to fully model a

Example 11-D—Creating a Thermodynamically Similar Model

Q

A proposed design has a dual-fan dual-duct system as in Design A. Some building simulation programs are able to model only single-fan dual-duct systems as represented in Design B. The dual-fan system is more energy efficient than the single-fan system because the heating coil is not heating relatively cool outdoor air when the outdoor air damper is open (economizer cycle). How would the proposed design be modeled using the ECB method?



A

A thermodynamically similar model to the dual-fan dual-duct system can be created by running the single-fan dual-duct model twice: once under normal conditions and recording all outputs except heating outputs, and then a second time with no outdoor air and recording only the heating outputs. The combined recorded outputs capture the simultaneous cooling and re-heating aspects as well as the benefits of higher air temperatures entering the heating coil.

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component or system of the proposed design. If this means that a reasonable calculation of the design energy cost cannot be made, then the best solution is to seek a different program that has the needed capabilities. In special cases, however, with the approval of the authority having jurisdiction, there are some alternatives to using a different program (Table 11.3.1-14a). One alternative, discussed in the previous paragraph, is to ignore the system in the model, provided this does not affect the modeling of trade-off measures. A second alternative is to apply engineering judgment and to model the component or system using a thermodynamically similar model that is within the capabilities of the program being used. This requires a thorough understanding of the algorithms of the simulation program and the thermodynamic characteristics of the component being modeled, but in many cases, it can be accomplished without compromising accuracy. It makes little sense, though, to use an alternate program for a component if it means losing the interactive capabilities of the hourly modeling tool. Consequently, this is generally not recommended.

A third alternative is simply to model the system or component as if it were the base case system defined for the budget building design. Of course, this alternative is only allowable when the system or component meets the prescriptive requirements of the Standard. Also, this alternative is not preferred, as the intent is to model the actual proposed design. The general rule, therefore, is if a simulation program can't model a component, then the component must not be given any credit for trade-offs.

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Application Examples

The following tables and examples illustrate how the various ECB method rules are applied in typical situations.

Newly Conditioned Space or a New Building

When a mechanical system is added to an unconditioned building, such as a remodel of a warehouse into a restaurant, the building is treated as a new building (§ 4.1.1.5). All building components need to be brought up to the Standard's requirements. Using the ECB method, trade-offs can be made among the non-mandatory building features as long as the design energy cost is less than the budget energy cost.

New Building with Unconditioned Space

Though an unconditioned building is outside the scope of this Standard, unconditioned spaces that are part of conditioned buildings are within the Standard's scope. The unconditioned space will have lighting requirements and this interior lighting can be traded off within the scope of the ECB method. The wall separating the conditioned from unconditioned spaces is a semi-exterior wall and has less stringent insulation requirements than an exterior wall (§ 5.1.1). Thus, the unconditioned space needs to be part of the proposed design and budget models.

Remodel of Existing Buildings

Recognizing that the incremental cost of improving the energy features of existing buildings is substantially greater than similar measures adopted during the design of new buildings, the Standard is less stringent for remodels as compared to new buildings. The main guidance is that the new systems should not consume

Table 11-D—ECB Modeling Considerations, Newly Conditioned Space or New Building

Component	*Design Energy Cost Model*	*Budget Energy Cost Model*
Mechanical	Existing or as designed except conditioned space will be modeled as both heated and cooled. See Table 11.3.1-1a, -7a, and -8a.	§ 6 requirements. See § 11.3.2 for selection of system type. Fan power the lesser of the design or what is required in § 6.5.3.1.
Envelope	Existing or as designed according to Table 11.3.1-5a Modeled reflectance = 0.3 unless tested reflectance > 0.7, and tested absorptance > 0.75, then modeled reflectance = 0.45	§ 5 requirements. Identical to design except: U-values from § 5.5; no overhangs; reflectivity = 0.3; WWR the lesser of design or § 5.5.4.2.1 and 5.5.4.2.2 maximum WWR; SHGC = maximum allowed. See Table 11.3.1-5b.
Service Hot Water	Existing or as designed. See Table 11.3.1-11a.	§ 7 requirements. Same as design except where § 7.3 applies. See Table 11.3.1-5b.
Lighting	Existing or as designed. See Table 11.3.1-6a. Can include daylighting controls. Occupancy sensors not modeled.	LPD based on either whole building or space-by-space method. Additional exempt lighting in design also modeled (see § 9.5). Minimal lighting controls. See Table 11.3.1-6b.

Table 11-E—ECB Modeling Considerations, Unconditioned Space

Component	*Design Energy Cost Model*	*Budget Energy Cost Model*
Mechanical	Let unconditioned zone temperature float.	Let unconditioned zone temperature float.
Envelope	As designed. See Table 11.3.1-5a.	Envelope surface between unconditioned space and outdoors is modeled as designed. Wall between conditioned and unconditioned zone meets semi-exterior wall U-factor requirements and has the same heat capacity as the proposed design model.
Service Hot Water	As designed. See Table 11.3.1-11a.	Same as design except where § 7.5 applies (boiler is serving both service hot water and space heating loads). See Table 11.3.1-11b.
Lighting	As designed. See Table 11.3.1-6a. May include daylighting controls. Occupancy sensors not modeled.	LPD based on either whole building or space-by-space method. Additional exempt lighting in design also modeled § 9.5. Minimal lighting controls. See Table 11.3.1-6b.

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more energy than the currently existing systems. When equipment is replaced, the new equipment must comply with the Standard. When 50% or more of the luminaires in a space are replaced, the lighting power density of the space must comply with the lighting power density requirements of § 9. The ECB method would typically be used when more than one type of building component is being remodeled and trade-offs between components can be made. The simpler prescriptive approach would be used if only one building component was being altered.

Addition to Existing Space

The computer simulation model of an addition can be simplified if just the addition can be described rather than having to simulate the addition and the existing building receiving the addition. A simplified model that considers only the addition is acceptable if: (1) there is essentially no heat transfer between the addition and the existing building; (2) there is a separate HVAC system so that HVAC loads and part-load performance are unaffected by the existing building; and (3) adequate adjustments are made to block rates.

A block rate varies depending upon the amount of energy consumed. Since the rate is a function of overall site consumption, the energy costs attributable to an addition must use rates that take into account the base consumption of the existing building and the consumption of the addition. The previous year's monthly energy consumption adjusted by heating degree-days and cooling degree-days along with the energy consumption outputs from the simulation of the addition should provide sufficient consumption estimates for calculating block rates.

When there are energy features traded off between the existing building and the addition, these trade-offs are evaluated on the basis of energy consumption, not annual energy cost.

Core and Shell Building

For showing compliance of a core and shell design, the tenant finish is treated as minimally compliant. Thus, the tenant finish assumptions are identical in the proposed design and the budget models. Since most of the connected lighting load will be in the tenant finish, the lighting system will be identical in proposed and budget models. In general, the ECB approach will not be taken unless a mechanical system is installed. Otherwise, the envelope has little room for trade-off.

Tenant Improvement

Tenant improvements are treated as a remodel. Typically, the prescriptive method is used to show compliance because the integrated design benefits provided by the ECB method are of limited value for tenant improvement projects. However, using the ECB Method, it's possible to gain concessions from the Standard when efficient components or controls strategies are installed.

Table 11-F—ECB Modeling Considerations, Remodeled Building

Component	*Design Energy Cost Model*	*Budget Energy Cost Model*
Mechanical	Descriptive of existing and new components. See Table 11.3.1-10a.	New equipment will meet the efficiency requirements in § 6. Existing equipment shall be identical to that described in the proposed design model.
Envelope	Envelope described as proposed.	For existing building envelopes: Envelope components, areas, and properties shall be described as the building existed before remodeling (see Table 11.3.1-5b). If the opaque envelope assemblies are altered, their U-factors shall be as described as in § 5.1.3, § 4.1.1.4, and § 4.2.1.3.
Service Hot Water	As designed. See Table 11.3.1-11a.	Same as design except where § 7.5 applies (boiler is serving both service hot water and space heating loads). See Table 11.3.1-11b. The combined boiler is modeled as a separate space heating boiler and hot water heater with minimum allowed efficiencies.
Lighting	As designed. See Table 11.3.1-6a. Can include daylighting controls. Occupancy sensors not modeled.	Spaces or rooms that have less than 50% luminaires replaced can be modeled by existing lighting power density (LPD); see § 9.1.2. Otherwise the LPD is based on either whole building or space-by-space method; see Table 11.3.1-11b. Additional exempt lighting (see § 9.5) in design is also modeled.

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Table 11-G—ECB Modeling Considerations, Additions

Modeling Considerations	*Modeling Selection*
Same HVAC schedules and temperature setpoints on either side of common wall between addition and existing building. Addition has separate mechanical system. Adjustments have been made for block rates.	Addition may be simulated without existing building. Common wall is defined as adiabatic (no heat transfer) or with extremely high U-factor. Table 11.3.1-2a.
Different HVAC schedules or temperature setpoints on either side of common wall between addition and existing building; or addition is served by an extension of an existing mechanical system. No central plant. Adjustments have been made for block rates.	Model addition and adjacent zone on other side of common wall. Model all zones served by mechanical systems that also serve the addition. The zones of the existing building should be described identically in both the proposed design and the budget models.
Opportunity to claim credit for efficiency improvements made to existing building to offset inefficiency of new addition; or addition served by system and plant of existing building; or block rates cannot be adjusted offline.	Model existing building and addition. Proposed design – model building as described by the proposed design documents. Ref. § 11.3. Budget model – Model addition and remodeled areas as minimally compliant as described in § 11.3. Unchanged areas in the existing building will be shown as the same in both proposed design and budget models. Also see above remodel discussion.

Table 11-H—ECB Modeling Considerations, Core and Shell Buildings

Component	*Design Energy Cost Model*	*Budget Energy Cost Model*
Mechanical	As designed. If not designed, the mechanical system will be identical to the budget model system. Conditioned space will be modeled as both heated and cooled in accord with Table 11.3.1-1a and Table 11.3.1-7a. See also Table 11.3.1-8a for guidelines on how to model thermal blocks when the system is not yet designed.	§ 6 requirements. See § 11.3.2 for selection of system type. Fan power is the lesser of the design or what is required in § 6.5.3.
Envelope	As designed. See Table 11.3.1-5a. Modeled reflectance = 0.3 unless tested reflectance > 0.7 and tested absorptance > 0.75, then modeled reflectance = 0.45.	§ 5 requirements. Identical to design except: U-values from § 5.5; no overhangs; reflectivity = 0.3; WWR the lesser of design or § 5.5.4.2.1 maximum WWR; SHGC = maximum allowed. See § Table 11.3.1-5b.
Service Hot Water	Existing or as designed. See Table 11.3.1-11a.	§ 7 requirements. Same as design except where § 7.5 applies (provides space heating and water heating). See Table 11.3.1-11b.
Lighting	General lighting for shell is not sufficient for application. LPD will be based upon the whole building method (Table 11.3.1-6a). If occupancy unknown, assume that it will be an office (Table 11.3.1-1a).	Lighting system should be identical to that in proposed design model of building.

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Case Study

To illustrate how to use the ECB method, this case study reviews the step-by-step procedures followed for an example building located in downtown Dallas, Texas (Zone 3A). These steps are:

1. Contact the local authority.
2. Comply with the Mandatory Requirements.
3. Create the proposed design simulation model.
4. Create the budget building.
5. Fine-tune the models.
6. Document compliance.

A completed Energy Cost Budget Basic Compliance form accompanies this case study.

Building Description

The building in this case study has seven above-ground stories and an underground garage. The building's footprint is 150 ft by 90 ft with the long axis oriented due east-west. The first floor contains retail spaces with large display windows that have overhangs projecting 10 ft on the south, east, and west exposures. The second and third floors contain offices that have similarly oriented overhangs, although the overhangs project only 5 ft. Above the offices are apartments on floors four through seven. To provide more daylight and fresh air, the four floors of apartments have two 20 ft by 30 ft notches taken out of the floor plan; therefore, these levels have 1,200 ft² less floor area than floors one, two, and three (See Figures 11-G and 11-H). The building also has an unconditioned stairwell.

This is a steel-framed building with steel stud walls with R-7 insulation and ⅝ in. sheetrock. The windows are single glazed with clear glass in all areas except the offices, which have single-pane windows with gray glass. All windows have thermally broken metal frames. Only the windows on the residential levels are operable.

Example 11-E—Existing + Addition Envelope Trade-Off

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The owner of an existing 5,000-ft² restaurant in Denver, Colorado, with no insulation in the envelope wants to add a 300-ft² greenhouse-style seating area. How can the ECB method be used to show compliance?

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By itself, the addition cannot comply with the Standard's Prescriptive Requirements. However, by insulating the roof of the existing restaurant, the energy consumption of the existing building can be reduced enough to offset the excessive energy consumption of the addition. Compliance is shown when the energy consumption of the existing restaurant with added insulation and the proposed addition is less than the sum of the energy consumption of the existing building without any changes and with an addition that meets the Standard's Prescriptive Requirements.

Thus the energy budget building would be the existing building as it is before the permitted changes. The addition would have the following characteristics:

- Envelope Prescriptive Requirements for Denver, CO (Table 5.5-5), apply.
- Total wall and roof areas are equal to the proposed wall and roof areas.
- Fenestration is the maximum allowable glazing area (40% of wall area and 5% of roof), with a maximum allowable U-factor and SHGC for the window frame type. Assuming metal (other) windows, this would be U = 0.55 Btu/h ·°F ·ft² and SHGC = 0.40. Maximum skylight area (5% of roof area), with maximum allowable U-factor (assuming skylight without curb) of U = 0.69 Btu/h ·°F ·ft² and SHGC = 0.39.
- Remainder of roof and wall areas (60% of wall area and 95% of roof area) meet the Prescriptive Requirements for opaque walls. The wall type (mass, metal frame, or wood frame) should reflect the type of construction for any walls on the addition (i.e., if the greenhouse-type glazing is placed on top of a masonry-type knee wall, the wall type in the energy budget model should be a mass wall).
- The common wall between the addition and the existing building can be treated as adiabatic. It should not be included as an exterior wall in the calculation of window wall ratio (WWR).

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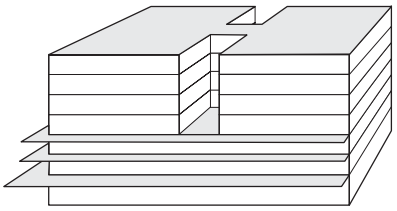

Figure 11-G—Case Study Isometric

A high-efficiency electric lighting system is used throughout the commercial sections of the building. Lighting power density is 1.38 W/ft² in retail areas, 1.16 W/ft² in office areas, 0.25 W/ft² in the underground parking, and 0.5 W/ft² in stairwells. The perimeter zones of the office have automatic daylight dimming controls.

Retail spaces are served by a four-pipe fan coil system so that they can be independently shut down if the stores' operating hours differ significantly. A variable air volume (VAV) air-handling system served by a centrifugal chiller and a boiler provides space conditioning in the office levels. The apartments are heated and cooled by four-pipe fan coil systems, which are also served by the chiller and boiler. The underground parking is ventilated during retail business hours.

A 160-ton, high-efficiency chiller with a rating of 0.6 kW/ton and a 2,250,000 Btu/h boiler serve all of the heating and cooling loads in the building.

Table D-1 gives the climatic characteristics of cities in the United States and around the world and contains cross-reference to which building envelope criteria table applies to that climate. Table B-1 shows Tallas belongs to climate zone 3A. The building envelope requirements that correspond to this climate are found in Table 5.5-3.

A review of the building envelope requirements and the Standard's other prescriptive requirements reveals that the proposed building does not meet the roof or wall U-value requirements and that the window glass has a too-high solar heat gain coefficient (SHGC). On the other hand, the building has extensive overhangs, daylighting controls, a low connected lighting load, an efficient chiller, and VSD pumps for chilled water, condenser water and hot water loops.

Step 1: Contact the Local Authority

Before using the ECB method for a proposed building, it's important to confirm that the authority having jurisdiction has approved the use of the method. Questions to ask of the authority having jurisdiction include:

- Is the ANSI/ASHRAE/IESNA 90.1-2007 ECB method accepted for showing compliance in this jurisdiction?
- Have there been any local amendments?
- Are there any special limitations or requirements on the use of the ECB method?
- Are there simulation programs or compliance shells that must be used?
- What climatic data are approved for use in this jurisdiction?
- What utility rate schedules are approved for calculating energy costs in this jurisdiction?

Step 2: Comply with the Mandatory Provisions

Some of the Standard's requirements are mandatory. Both the building design and the simulation used in the ECB method must comply with these requirements. See the technical chapters of this Manual (Chapters 5, 6, 7, 8, 9, and 10) for details about the Standard's Mandatory Requirements.

Step 3: Create the Proposed Design Simulation Model

The building simulation model should accurately capture the energy features of the building design. Accuracy, however, needs to be balanced against the time required to generate a reasonable model. The Standard gives guidance on the types of model approximations that are acceptable.

Building Envelope

Walls that are within 45 degrees of each other can be combined into a single wall having the same orientation. The thermal and optical properties of the envelope need to be accurately described. Definitions of walls must include thermal mass (specific heat and density) as well as resistance to heat flow (U-factor or R-value). Wall assemblies in the simulation model have to be built up out of a library of physical properties for different building materials.

Walls with parallel heat paths, such as the framing and the insulation, can be treated as two separate walls: one with just wood in the center of the assembly and the other with just insulation in the center. These two wall types are sized so that the wall section representing framing takes up the fraction of total wall area that corresponds to the framing fraction.

Some components that have parallel heat paths with widely diverging conductivities (such as steel frame wall sections) cannot be accurately modeled using the method described above. In this case, an effective thermal resistance for the assembly containing both the framing and the insulation should be used. Empirical values of the effective resistance of steel stud framing assemblies filled with

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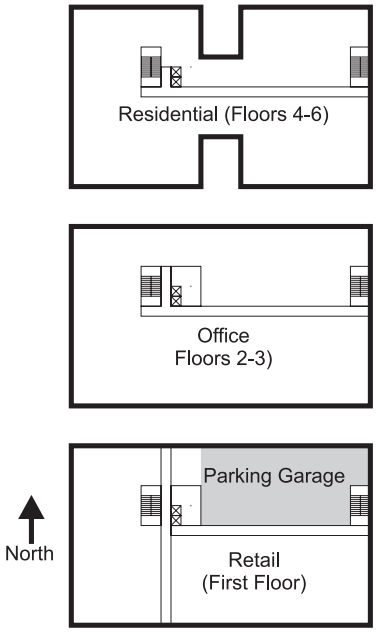

Figure 11-H—Case Study Floor Plans

insulation are given in Table A3.3 in Appendix A. The simulation program will have libraries of many common building materials including steel framing. However, these libraries contain only common constructions.

The wall section used in the proposed Dallas building is a combination of thermal properties of sheet metal with a Masonite backing, a metal-framed assembly that includes metal studs spaced 16 in. o.c., R-7 insulation, and 5/8 in. gypsum wallboard. The simulation program used will have libraries of many common building materials. The manufacturer of the metal cladding reports that the R-value of this product is 0.26 Btu/ft²·h·°F. The metal cladding is defined in the program and combined with the steel framing with R-7 insulation having an effective R-value of 3.5 Btu/ft²·h·°F and 5/8 in. gypsum wallboard with an R-value of 0.56. Thus the overall R-value of the opaque wall section is 0.26 + 3.5 + 0.56 = 4.32 Btu/ft²·h·°F. If the air film surface coefficients were included, the wall would be considered to have an overall R-value of approximately 5.17 Btu/ft²·h·°F. These are not included when creating wall assemblies, however, because the building simulation program calculates the air films separately.

Unless the building includes daylighting controls, windows can be grouped together into a larger effective window. Window, U-factor, SHGC, and visible transmittance need to account for the thickness of the frame and mullions and the type of spacers and thermal breaks in the frame. The NFRC rating should be used for any premanufactured windows. As with windows, skylights must be described in terms of the performance of the whole assembly including the skylight frame and curb. In the Dallas building, all the windows have a center-of-window U-factor of 1.09 Btu/ft²·h·°F, but when the heat losses from the aluminum frame are added, the windows have an overall U-factor of 1.22 Btu/ft²·h·°F. Appendix A contains a tabulation of default fenestration U-factors in Table A8.1A and default SHGC values in Table A8.1B.

The 10 ft overhangs over the retail windows and the 5 ft overhangs over the office windows are defined in the model. These overhangs influence solar heat gain; they also affect the amount of sunlight that will displace electric lighting in the perimeter office zones that have daylighting controls.

Lighting

The actual installed power of the electric lighting system must be shown in the proposed design simulation model. This differs from the calculation of connected luminaire wattage in the prescriptive application of the Standard, where the maximum rating of a screw base socket is used instead of the lamp wattage actually installed in the socket. In the proposed design, the designed wattage of a track lighting system is used rather than a minimum 30 W/lin ft of lighting track given in the prescriptive Standard. The lighting power should include the power consumed by ballasts as well as the lamps. Default tables are contained in the lighting section of this Manual; however, lighting technology has been rapidly changing and using the default tables may result in an overestimate of connected load. Note that many fluorescent ballast manufacturers are quoting open and enclosed ballast wattages. The open values should be used with strip and parabolic fixtures, while the enclosed values should be used for lensed fixtures.

In the proposed Dallas building, daylighting controls are defined for the perimeter office zones for which daylighting controls have been specified. The type of daylighting control (dimming versus on/off or step control) used for this project is dimming.

HVAC

The mechanical system should be modeled exactly as it is specified. Thus the default fan efficiency and static pressure contained in the simulation program should not be used for calculating fan energy. Residential and office spaces use four-pipe fan coil systems that are sized as they are on the plans. The VAV systems serving the office floors also make use of the actual equipment specified. In this case, both the supply and return fans have variable-speed drives to control flow.

Creating a separate simulated zone for each zone designed in a large building is time intensive and can only be done for zones having the same orientation, the same HVAC system, and the same space-

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use classification. Only one floor of the two office floors is modeled and a multiplier of two is applied. The entire interior core zone is treated as a single zone, although there is more than one VAV box controlling airflow into different sections of the core zone. This is allowed because the timing of loads in the zone is the same over the entire zone.

The ECB method allows the energy analyst to create occupancy and equipment schedules that they feel most closely represent the expected use of the building. These schedules have to be the same for both the proposed design and the budget building. Currently this has worked to the detriment of occupancy sensors or other lighting time clock controls—modeling these features is accomplished by changing the lighting schedule based upon assumptions about how many more hours the lights would be off as compared to occupants manually turning off the lights.

It is important to debug the proposed design before creating the budget building model. The budget building is supposed to deviate from the proposed design in those features that have specific requirements, such as envelope U-factor and SHGC, lighting power density, and mechanical system efficiency. The budget building and the proposed design should also differ where it is specifically agreed that the base case for energy compliance design does not include the efficiency option and the measure can be definitively modeled without generating assumptions about occupant behavior (for example, daylighting controls or demand-controlled ventilation).

Step 4: Create the Budget Building

The simulation model of the budget building is created by applying the Standard's prescriptive requirements to the proposed building design. If a compliance shell is available, it will automatically generate a budget building from the inputs for the design building model. If a compliance shell is not available, then you should use the procedure for creating the budget building that is described in § 11 of the Standard and the ECB compliance supplement.

The details below illustrate how to manually create the sample budget building model. To determine the characteristics of the budget building, fill out a set of the Standard's compliance forms, but replace the actual characteristics of the designed building with the minimally compliant values. Where there is no guidance from the Standard about which values should be used, then model the budget building with values identical to the proposed building. For example, in this case study, there is no requirement for the lighting power density in dwelling units (see exception (b) to § 9.1.1); therefore, the lighting power in the living spaces will be identical in both models.

Space-Conditioning Categories

The case study building has three space-conditioning categories:

- Residential spaces: the dwelling units on the apartment levels.
- Nonresidential spaces: office and retail spaces as well as nondwelling space on apartment levels (e.g., hallways).
- Unconditioned spaces: stairs and parking garage.

Walls

There are five wall types in the proposed building design. Three of these are considered either exterior or semi-exterior building envelope and are covered by requirements in the Standard. The other two wall types, exterior unconditioned and interior partitions, are not covered by the Standard and are identical in the budget and proposed design. These five wall types are described below:

- *Nonresidential exterior*: walls between the conditioned nonresidential spaces (including apartment hallways) and the outside.
- *Residential exterior*: walls between the conditioned space of the dwelling units and the outside. Note that the wall of the parking garage is considered exterior because the garage must be ventilated—either by natural or forced ventilation—to remove contaminants.
- *Semi-exterior*: walls between enclosed conditioned areas and unconditioned areas (for example, walls adjacent to the unheated stairwell). Semi-exterior walls are treated as exteriors for semiheated zones.
- *Unconditioned exterior*: there are no compliance requirements for unconditioned exterior walls. These wall properties will be the same in the budget and proposed building models.
- *Interior partitions*: walls between two conditioned zones. In general, there is little heat transfer through interior partitions unless operating schedules are markedly different. The Standard has no compliance requirements for interior partition walls, so these wall properties will be the same in the budget and proposed building models.

Figure 11-I shows the location of different wall types on the first floor. Note that the only semi-exterior wall is between the unconditioned stairs and the conditioned retail space. On the upper floors where the stairwell has conditioned space adjacent to three of the four walls, the stairwell is considered indirectly conditioned space; the wall between the stairwell and the outside is considered exterior.

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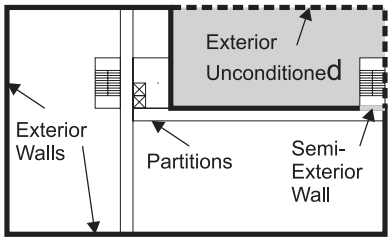

Figure 11-I—Wall Types, First Floor

Windows

There are different requirements for windows depending on the window frame type. The simulation program for model verification usually gives the window and wall areas for each zone and their orientations. Table 11-I compares the proposed and budget glazing types.

Overhangs are not in the budget building model. However, wherever the proposed design has interior shades or blinds, the budget model also has interior shades or blinds.

Lighting

The budget building lighting system can be calculated using either the building area method or the space-by-space method. The building area method requires fewer inputs (see Table 9.5.1 of the Standard). For simplicity's sake, this is the method used in this case study. If the building area method is used, it must be used throughout the whole project. The space-by-space method cannot be used for one floor and the building area method for the other floors. The space-by-space method is often used for retail projects with large amounts of display lighting because it offers an additional allowance for display lighting of up to 1.6 W/ft² for most retail spaces or up to 3.9 W/ft² for displaying fine merchandise (see § 9.6.2, Additional Lighting Power). The budget building would allot the lesser of the budget display lighting budget or the maximum display lighting allotment in addition to the lighting power density specified for general retail lighting in the space-by-space LPD table (Table 9.6.1).

Table 11-J compares the proposed and budget lighting power densities for the different spaces.

Even though the parking garage is considered unconditioned and unenclosed, it is still an interior space for lighting purposes and is available for lighting power trade-offs with the rest of the building. Note that the multi-family hallway is considered separately from the apartments. The hallway is considered a nonresidential space with limitations on lighting power. The dwelling units inside the building are exempt from lighting power density requirements and thus the proposed design wattage and budget lighting wattage are identical.

Mechanical

Defining the Mechanical System

The type of mechanical system used in the budget building is based upon the following evaluation of the systems in the design building:

- Does the system serve residential or nonresidential occupancies?
- Is the system single-zone or multi-zone?
- Is the condenser air-cooled or water-cooled?
- Is heating generated by heat pump, electric resistance, or fossil fuel?

To define the air-handling system for the budget building, answer these four questions and consult Figure 11-F (Figure 11.3.2 in the Standard) and **Error! Reference source not found.** (Table 11.3.2A in the Standard).

In the proposed building, all of the

Table 11-I—Comparison of Proposed and Budget Window Solar Heat Gain Coefficients

Space Category	*Orientation*	*Wall Area*	*Window Area*	*Window-Wall-Ratio*	*Proposed U-Value/SHGC*	*Budget U-Value/SHGC*
Residential	North	6,960	1,742		1.22/0.82	0.65/0.25
	Non-North	30,360	5,389		1.22/0.82	0.65/0.25
Residential total		36,960	6,591	18%		
Nonresidential						
Retail	North	1,600	534		1.22/0.82	0.65/0.25
	Non-North	4,293	2,920		1.22/0.82	0.65/0.25
Office	North	3,200	1,000		1.22/0.43	0.65/0.25
	Non-North	8,587	2,054		1.22/0.43	0.65/0.25
Nonresidential total		17,680	6,508	37%		
Totals		127,259	124,520			

Table 11-J—Comparison of Proposed and Budget Lighting Power

	PROPOSED			BUDGET		
Area Description	*Area*	*Watts*	*LPD*	*Watts*	*LPD*	
Nonresidential						
Parking	15,700	3,925	0.25	4,710	0.30	
Retail	11,300	15,594	1.38	16,950	1.50	
Office	27,000	31,320	1.16	27,000	1.00	
Apartment units	43,600	71,940	1.65	71,940	1.65	
Multi-family hallway	5,600	4,480	0.80	3,920	0.70	
Totals	103,200	127,259	1.23	124,520	1.21	3%

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cooling systems are served by a water-cooled chiller; therefore, the condenser cooling source is Water/Ground and the system types considered are in the top half of the figure. All of the systems in the proposed building use hot water from the natural gas boiler; therefore, the heating system classification is fossil fuel and the potential choices for systems are system 7 (a four-pipe fan coil system) or system 2 (a variable air volume system with reheat). The zoning classification choices of "single-zone residential," "single zone nonresidential," and "all other" define the system. The retail stores are single-zone systems so as single-zone nonresidential systems they are defined as system 7 (four-pipe fan coil). The office spaces are on a multiple-zone air handler; therefore, they are in the "all other" system category and the fan system for the offices would be system 2 (VAV system with reheat). The apartment HVAC is defined as residential single-zone systems and is mapped to system 7 (four-pipe fan coil).

Fans

The fans in the budget building's HVAC systems should have the same bhp/cfm ratio as the fans in the design building model unless the proposed building's fans exceed the bhp/cfm ratio described in § 6.5.3 of the Standard. The fan systems in the proposed building have a relatively low static pressure and thus are not affected by the bhp/cfm ratio limitation, so that the budget building's bhp/cfm ratio is the same as that of the design building's fans. The proposed building does have variable-frequency drives on the supply fans and return fans that serve the office VAV system. However, variable-speed drives are not applied on VAV fans in the budget model until the fan size exceeds 15 hp. The office system fans in the budget building, therefore, are modeled as forward-curved centrifugal fans with inlet vanes.

Controls

All systems in the building have setback thermostats. The temperature schedules reflect that they are used to turn off commercial fan systems during unoccupied hours and to set back the residential temperatures at night. Since the office fan systems have flow rates in excess of 10,000 cfm, the budget building model of these HVAC systems includes optimal start control.

The energy management system designed for the proposed building includes direct digital control of the VAV boxes in the offices. Because there is DDC control at the zone level, the static pressure setpoint for control of the supply fan inlet vanes shall be reset as described in § 6.5.3.2.3 of the Standard.

Chiller Sizing

Since the chiller size that will meet the loads in the budget building is less than 300 tons, only one chiller is specified (see Table 11.3.2B in the Standard). Because the chiller is between 100 and 300 tons, it will be modeled as a screw compressor in the budget building simulation (see Table 11.3.2C in the Standard). When a simulation was performed on the proposed building design with the chiller autosized, the maximum chiller loads were calculated to be 125 tons. The 160-ton chiller selected for the proposed building had a combined safety margin and convenient sizing increment of 28% above the maximum load of 125 tons. The size of the budget chiller is found by autosizing the chiller in the budget building model and then selecting a chiller that is oversized by the same margin as in the proposed building design, in this case 28% greater than the maximum chiller load. The maximum load for the budget building was found to be 104 tons and it was increased in size by 28% to 133 tons. This assures comparability between the two systems based upon efficiency of the system rather than sizing issues.

Boiler Sizing

Boiler sizing is accomplished in the same way as chiller sizing: the boiler in the budget building is oversized by the same percentage 28% as the boiler in the proposed building model. The boiler in the budget building is required to be modeled as a natural draft type regardless of size. Because the maximum boiler load is greater than 600,000 Btu/h, two equally sized boilers, each rated at 768,000 Btu/h, are defined for the heating plant.

After the plant has been sized, the simulations can be run for both proposed and budget buildings with fixed boiler and chiller sizes.

Step 5: Fine-Tune the Models

After both models have been run, the results are analyzed to check for errors and to verify compliance. In some cases, unmet load warnings will indicate the number of hours that the system or plant was unable to meet the loads placed on them. This is commonly found in morning start-up situations where the pick-up loads cannot be met in a single hour.

If the number of hours that loads are unmet by either the systems or plant differs by more than 50 hours between the budget and proposed design models, these simulation results will not be accepted as valid. The best way to deal with this problem is to confirm that the sizing method of both the budget and proposed system is similar. Alternatively, these results may indicate that some part of the HVAC system is undersized and may require redesign. As shown on the sample Energy Cost Budget Compliance report, there are no hours of heating or cooling

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loads unmet for both the proposed and budget models.

Step 6: Document Compliance

The two-page Energy Cost Budget (ECB) Compliance report summarizes the finding that the proposed Dallas building would have lower energy costs than a minimally compliant building.

Dated building plans must accompany the compliance materials. The plans should be annotated with lines demarcating thermal blocks used in the simulations and the zone names used in the simulation. A detailed description of inputs referenced to page sections and schedules must also be on the plans. A cross-reference must be created between the equipment in the mechanical schedule and the equipment defined in the building model inputs.

A written description of those energy features that either exceed the minimal requirements or that are less than the requirements must be documented. This shows the plans checker which items are involved in the trade-offs.

If there is a change in the proposed design, it is necessary to re-run the analysis, unless approved by the local authority having jurisdiction. It is within the authority of the local building official to require that the analysis be re-run for any changes to the final plans.

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Energy Cost Budget (ECB) Compliance

Project Name:	Mixed use commercial building w/apts.		
Project Address:	125 E. 5th Street (Corner of 5th and Beech St)	Date:	6/11/2007
Designer of Record:	Joe Smith, AIA	Telephone:	(214) 555-1234
Contact Person:	James Calhoun, P.E.	Telephone:	(214) 555-4321
City:	Dallas, TX	Principal Heating Source: ☒ Fossil Fuel ☐ Electricity ☐ Solar/Site Recovered ☐ Other	
Weather Data:	Ft Worth TMY2		

Space Summary

Building Use	Conditioned Area (ft²)	Unconditioned (ft²)	Total
Retail	11,300		11,300
Office	27,000		27,000
Residential	49,200		49,200
Parking		15,500	15,500
Stairs		200	200
Total	87,500	15,700	103,200

Advisory Messages

	Proposed Building Design	Budget Building	Difference Proposed – Budget
Number of hours heating loads not met (system/plant)	1/0	0/0	1/0
Number of hours cooling loads not met (system/plant)	1/0	0/0	1/0
Number of warnings	0	0	0
Number of errors	0	0	0
Number of defaults overridden	0	0	0

Compliance Result

The design detailed in the above referenced plans complies with the mandatory requirements of the ANSI/ASHRAE/IESNA 90.1-2007 Standard and the Design Energy Cost does not exceed the Energy Cost Budget. Therefore this design **DOES COMPLY** with the ANSI/ASHRAE/IESNA 90.1-2007 ECB Compliance Methodology.

Individual certifying authenticity of the data provided in this analysis:

Signature: James Calhoun	Title: James Calhoun, PE

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Energy Cost Budget (ECB) Compliance

Project Name:	Joe Smith, AIA	Telephone:	(214) 555 4321
Contact Person:	James Calhoun, PE	Telephone:	(214) 555 4321

Energy Summary by End Use

End Use	Energy Type	Proposed Building Energy (10^6 Btu/yr)	Proposed Building Peak (10^3 Btu/h)	Budget Building Energy (10^6 Btu/yr)	Budget Building Peak (10^3 Btu/h)	Proposed / Budget Energy (%)
Lighting – conditioned	Elec	1034.1	288.5	1056.5	292.9	98%
Lighting - unconditioned	Elec	119.6	20.0	143.5	15.6	83%
Space heating (1)	Nat. Gas	602.1	2,286.0	375.9	1,664.0	160%
Space heating (2)						
Space cooling	Elec	627.5	248.8	829.9	272.7	76%
Pumps	Elec	46.9	13.3	116.5	18.8	40%
Heat rejection	Elec	169	26.6	153.2	23.2	110%
Fans – interior ventilation	Elec	301.6	115.1	195.1	96.4	155%
Fans – interior exhaust						
Fans – parking garage	Elec	151.4	17.3	151.4	17.3	100%
Service water heating	Nat Gas	95.2	36.0	95.2	36.0	100%
Office equipment	Elec	857.3	206.5	857.3	206.5	100%
Elevators & escalators						
Refrigeration (food, etc.)						
Cooking (commercial)						
Total Building Consumption		4,004.7		3,974.5		101%

Energy Summary by End Use

	Proposed Building Energy (10^6 Btu/yr)	Proposed Building Cost ($/yr)	Budget Building Energy (10^6 Btu/yr)	Budget Building Cost ($/yr)	Proposed / Budget Energy (%)	Proposed / Budget Cost (%)
Electricity	3045.8	64,928	3226.3	69,704	93%	93%
Natural gas	697.3	3,424	471.1	2,499	137%	137%
Other fossil fuel						
District steam						
Total nonsolar						
Solar or site recovered						
Total Including Solar	3743.1	68,352	4,060.0	72,204	98.6%	94.7%

* These results use assumptions for showing compliance during a typical year; actual energy costs may be substantially different.

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Considerations for the Adopting Authority

Notes for Adopting Authorities (§ 11.2.1 Note)

When an authority adopts the Standard for use as a code, the ECB method becomes part of that code. Because the ECB Method relies on sophisticated computer simulation programs and procedures, it is important that the adopting authority consider how best to implement the ECB Method. This section discusses some of the issues and makes some recommendations for implementation.

ECB Method Pros and Cons

Occasionally, adopting authorities may be asked to consider local amendments to the Standard that would modify or even eliminate the ECB method. The following are some of issues related to this question and pros and cons for each of these issues.

User Sophistication

PRO: Encourages integrated building design. Designers who have the requisite training and expertise can use the ECB method to design more sophisticated, better-integrated buildings and energy systems, often leading to reductions in first costs or to more reliable energy performance.

CON: Requires sophistication to use. A certain degree of experience in computer simulation techniques is required to do a set of proper ECB method calculations. As with any computer modeling, a simulation program's outputs are only as good as the inputs. Users of the ECB Method should have solid engineering training and experience.

Enforcement Sophistication

PRO: Can be easier to enforce. The computer tools used for the ECB method can actually make the enforcement process easier than when the prescriptive methods are used; some of the recommendations that follow explain how this can be done.

CON: Requires sophistication to enforce. The building officials who approve permits for buildings complying under the ECB method need some sophistication in building energy analysis. They must be able to independently judge whether the analysis is acceptable, instead of merely relying on the engineering judgment of the energy analyst. If the ECB Method is not well enforced, it could become a vehicle for circumventing the Standard.

Better Buildings

PRO: May produce more cost-effective buildings. The trade-offs give designers the flexibility to make cost/benefit trade-offs among efficiency choices. The ECB method also allows designers the flexibility to deal with unique design problems that might be costly to solve under the prescriptive requirements.

CON: May produce buildings that use more energy than buildings using prescriptive design criteria. Because of the trade-off capabilities of the ECB method, designers are free to design "close to code," that is, to optimize the energy systems so that the overall performance closely matches the minimum allowed by the Standard. Under the prescriptive method, it is often more difficult to do this, potentially resulting in buildings that use less energy than with the ECB Method.

Aging of the Standard

PRO: None. There is no advantage to this situation; rather, it points to the necessity of maintaining the Standard so that it continues to reflect current construction practices.

CON: As the Standard ages, it may become easier and less expensive to exceed some areas of the prescriptive requirements. ECB allows designers to take advantage of these discrepancies by increasing the efficiencies of these systems and cutting back the efficiencies of other, more costly systems.

Gamesmanship

PRO: Encourages creativity. The flexibility of the ECB method allows designers to try combinations of systems and features that may work better than standard design approaches or to take advantage of newer technologies that were not anticipated by the prescriptive requirements.

CON: Encourages gamesmanship. By allowing many kinds of trade-offs, the ECB method may encourage some users to try to circumvent worthwhile aspects of the prescriptive requirements.

Cheating

PRO: Cheating can be detected. Many of the recommendations of this section are designed to help adopting authorities to set up the ECB method in such a way as to minimize cheating by using the computer simulation tools as an aid to enforcement.

CON: Encourages cheating. Some users might use the complexity of the method to disguise noncompliance with the Standard.

Innovation

PRO: Encourages innovation. Although the ECB method does not give trade-off credit to behavioral or operational energy efficiency measures, it does not prohibit them. Designers and owners may still implement them and benefit from the results. Furthermore, the ECB Method does credit higher efficiency equipment and integrated systems design and allows trade-offs that are not possible under the prescriptive methods. The ECB Method allows a much greater ability to optimize

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the building design to meet specific programmatic requirements and reduce first costs.

CON: Restricts innovation. The ECB method does not allow unlimited trade-offs for every design approach, measure, or technology that might save energy. The rules constrain trade-offs to types of measures that can be conservatively demonstrated to produce reliable savings over the life of the building. This conservatism in the Standard fails to reward measures that depend on behavioral or operational activities, which could discourage their application.
To be effective, the ECB method must be adopted and implemented in ways that realize these advantages and avoid the problems discussed above. These adoption considerations are discussed in the next section.

Adoption Considerations
Adopting authorities are urged to consider several important issues to ensure that the ECB method will be properly implemented and enforced.

Approve Simulation Programs
The Standard requires designers to use a simulation program approved by the adopting authority (see § 11.2.1.1). At least one computer simulation program should be approved. The approval indicates that the program meets the minimum requirements (see Minimum Modeling Capabilities earlier in this chapter [§ 11.2.1]) and has the ability to model specific requirements outlined in the Standard. There are many suitable simulation programs on the market, some of which are already in common use by designers for other purposes.

Adopt a Compliance Supplement
A compliance supplement supports the Standard's Energy Cost Budget method by laying out detailed analysis rules for calculating the energy cost budget and the design energy cost, as well as other ECB method requirements. The compliance supplement is intended primarily for the developers of compliance shells and helps to ensure that their programs work properly. A sample compliance supplement is included as an Appendix to this Manual

Adopt a Compliance Shell
A compliance shell is a front-end to the simulation program that organizes the ECB method input and output, provides standardized compliance reports, and automatically generates the budget building design based on the proposed design. It is possible for the ECB Method to be used without a compliance shell, but it would be much more difficult to detect analysis errors or to identify necessary efficiency features in the design. The compliance shell automates much of the analysis work, especially for the budget building design, and makes it easier for users to apply the ECB Method rules. The shell also makes it easier for local authorities to check and approve ECB Method permit submittals. By the time this Manual is published, there should be several compliance shells on the market. Adopting authorities may prefer to approve more than one compliance shell to give users more choice and to encourage competition between shell developers

Approve Standard Compliance Forms
Standard compliance forms report on the energy cost budget, the design energy cost, and the energy-related features of a proposed building. Standardized forms make sure that designers submit all the information needed for approval and make it easier for enforcement authorities to review and approve the ECB calculations that are submitted. The forms also make it easier for the enforcement authorities to verify that the necessary energy features of the design are installed in the finished building. At the end of this chapter, there is a sample compliance form for the ECB Method. In addition, the model compliance supplement in the Appendix describes the desired features of ECB compliance forms to be generated by a compliance shell.

Approve Climate Data
The Standard requires designers to use climate data approved by the adopting authority (see § 11.2.2). Furthermore, the ECB method relies on good climate data that are hourly and represent the long-term expected weather conditions for each climate location. The representativeness of the climate data can be ensured in several ways. An average year's weather data can be selected from several years of weather data by noting which year's data (heating degree hours, cooling degree hours, or other parameters) are closest to the long-term average. The typical meteorological year (TMY) method of generating a representative climate dataset selects typical months that are close to the long-term monthly average and combines these typical months together. A TMY file may be the combination of typical months' data (i.e., Jan 1962, Feb 1988 etc.). A smoothing algorithm is applied to discontinuities between months. This format creates a representative year's data while maintaining the climatic transients contained within a month.

Representative climatic datasets are available from several sources: ASHRAE sells a CD-ROM with version 2 of the Weather Year for Energy Calculations (WYEC2) for 52 U.S. and 5 Canadian

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locations.[12] The National Renewable Energy Laboratory (NREL) freely distributes version 2 of the Typical Meteorological Year (TMY2) from their website and on CD-ROM.[13] Canadian Weather [year] for Energy Calculations (CWEC) data based on the TMY algorithm can be purchased from Environment Canada for 47 Canadian locations.[14]

The adopting authority can make the enforcement job easier by approving the allowable climate data. If the jurisdiction is large (for example, a state), there may be many climate zones with associated climate files for each climate zone. Given the "typical" or average nature of these climate files, the designer may use different design climate data for sizing equipment to maintain comfort through extreme conditions.

Approve Purchased Energy Rates

The Standard requires designers to use purchased energy rates approved by the adopting authority (see § 11.2.3). The costs of electricity, gas, oil, and other energy sources are important determinants of compliance under the ECB method. Because energy rate structures are highly variable, and energy rates change over time, it is recommended that adopting authorities approve a limited number of standard rates that can be expected to apply broadly to nonresidential buildings over the course of their lifetimes. These may include rate structures that are usual among the local utilities, such as fixed charges, declining blocks, seasonal adjustments, demand charges, or even time-of-use charges. It is recommended that adopting authorities approve an up-to-date costs as the default purchased energy rates, unless they make an intentional policy choice to use other rates. Up-to-date costs may be found on the Energy Information Administration (EIA) website: http://www.eia.doe.gov/cneaf/electricity/epa/epat7p4.html.

Given the current rapid rate of change in utility pricing, adopting authorities should exercise caution before approving actual, current utility rates for use with the ECB method. In any case, the ECB Method requires that the same purchased energy rates be used for both the budget and design cost calculations; analysts may not, for example, use a flat rate for the energy cost budget calculation and a time-of-use rate for the design energy cost calculation.

Whether or not these recommendations are implemented by the adopting authority, it is important that both users and enforcement personnel for the energy code be made familiar with the adopting authority's decisions on these matters. This could be done as a local addendum to this chapter, as a separate notice, or through some other mechanism that will be readily available to those who need the information.

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12. ASHRAE, *Weather Year for Energy Calculations 2* Data and Tool Kit CD-ROM. See the ASHRAE website for more information, http://www.ashrae.org/.

13. National Renewable Energy Laboratory, *User's Manual* forTMY2sTypical Meteorological Years Derived from the 1961-1990 National Solar Radiation Data Base, William Marion and Ken Urban http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/.

14. Environment Canada, Canadian Weather Energy and Engineering Data Sets (CWEEDS) and Canadian Weather [year] for Energy Calculations (CWEC) User's Manual, Atmospheric Environment Service, Downsview, Ontario, 1993. http://www.cmc.ec.gc.ca/climate/cwec.htm.

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Compliance Form

Notes for Simulation Program Developers

Successful implementation and use of the ECB method depends upon a good simulation program and a good compliance shell. Although some compliance shells may be developed by public sector entities, it is expected that most shells will be software products developed by private entities for sale to designers who wish to use the ECB Method to optimize their building designs and to meet the requirements of the Standard. Because the adopting authorities must approve the software, there is a need for collaboration between them and the software developers. The collaboration begins when the adopting authority approves a compliance supplement that spells out the analysis rules that must be implemented in the compliance shell. In many cases, the software developers will have the most intimate knowledge of these rules, so there is an opportunity for them to provide advice and input to the adopting authorities' compliance supplements. The adopting authorities, in turn, need to provide clear guidance in the compliance supplement to software developers on their intent and interpretation of the Standard, especially if there are any locally adopted amendments. The compliance supplement provides a level playing field for all software developers who wish to develop competing compliance shells, so it is in everybody's interest to see that it is well implemented.

There will be opportunities for creative software developers to implement the ECB method in new ways, for example, by bundling a compliance shell with an HVAC system design package. There may also be opportunities, through creative user interface design, to make the ECB Method more accessible to a wider audience than the energy simulation specialists who have been the primary users in the past. Software developers will also have the opportunity to extend the scope of the ECB Method as they expand the capabilities of their simulation engines. In some cases, this may entail the adoption of exceptional methods of calculation by the adopting authority, but the ECB Method provides for these kinds of advances (§ 11.2.5).

The following page provides a sample compliance form, the Energy Cost Budget (ECB) Compliance Report form, that conforms to the requirements of the Standard. A modifiable electronic version is included on the CD that accompanied this Manual, and is also available for free download from the ASHRAE website.

This form is intended for use with the ECB method when a compliance shell is not used. If a compliance shell is used, it should automatically generate a version of the compliance report. If this form is used instead, the user should fill in the form using information taken from the output reports of the simulation program.

In addition to this form, the user should submit completed forms from the other chapters of this Manual. Those forms document the proposed design and its features, and they also make it clear where the proposed design under the ECB method differs from the prescriptive requirements. Finally, as noted at the bottom of this form, the user should provide a list that describes all instances where input assumptions differ between the budget building and proposed design runs.

The ECB Compliance report has several sections designed to make clear to the enforcement personnel what the building characteristics are and how the ECB Method has been applied to it:

- *Project Name and Information*: This section begins with a basic statement that the project complies with the Standard, and notes the date of the plans upon which the compliance runs are based. This section also records basic information about the project, the people involved, the heating fuel, and the weather data used for the ECB analysis. There is also space to summarize the areas and uses within the building.
- *Advisory messages*: This section reports information from the simulation runs that is helpful in identifying modeling problems or special situations.
- *Compliance Result*: This final section is prepared by the person responsible for the compliance submittal to the authority having jurisdiction.
- *Energy and Energy Cost Summary*: These sections summarize the energy use breakouts by end use and by fuel type. They also show the percent difference between the proposed and the budget buildings. When the percentage value is less than 100%, then the proposed design is better than the budget. For compliance, the Cost % difference for "Total incl. Solar" must be less than or equal to one.

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Energy Cost Budget (ECB) Compliance Report

Project Name:	
Project Address:	Date:
Designer of Record:	Telephone:
Contact Person:	Telephone:
City:	Principal Heating Source: ☐ Fossil Fuel ☐ Electricity ☐ Solar/Site Recovered ☐ Other
Weather Data:	

Space Summary

Building Use	Conditioned Area (ft²)	Unconditioned (ft²)	Total
Total			

Advisory Messages

	Proposed Building Design	Budget Building	Difference Proposed/Budget
Number of hours heating loads not met (system/plant)			
Number of hours cooling loads not met (system/plant)			
Number of warnings			
Number of errors			
Number of defaults overridden			

Compliance Result

The design detailed in the above referenced plans complies with the mandatory requirements of the ANSI/ASHRAE/IESNA 90.1-2007 Standard and the Design Energy Cost does not exceed the Energy Cost Budget. Therefore this design **DOES COMPLY** with the ANSI/ASHRAE/IESNA 90.1-2007 ECB Compliance Methodology.

Individual certifying authenticity of the data provided in this analysis:

Signature	Title:

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Energy Cost Budget (ECB) Compliance

Project Name:	
Contact Person:	Telephone:

Energy Summary by End Use

End Use	Energy Type	Proposed Building		Budget Building		Proposed / Budget Energy (%)
		Energy (10^6 Btu/yr)	Peak (10^3 Btu/h)	Energy (10^6 Btu/yr)	Peak (10^3 Btu/h)	
Lighting (conditioned)						
Lighting (unconditioned)						
Space heating (1)						
Space heating (2)						
Space cooling						
Pumps						
Heat rejection						
Fans (interior ventilation)						
Fans (interior exhaust)						
Fans (parking garage)						
Service water heating						
Office equipment						
Elevators & escalators						
Refrigeration (food, etc.)						
Cooking (commercial)						
Total Building Consumption						

Energy Summary by End Use

	Proposed Building		Budget Building		Proposed / Budget	
	Energy (10^6 Btu/yr)	Cost ($/yr)	Energy (10^6 Btu/yr)	Cost ($/yr)	Energy (%)	Cost (%)
Electricity						
Natural gas						
Other fossil fuel						
District steam						
Total Nonsolar						
Solar or site recovered						
Total Including Solar						

* These results use assumptions for showing compliance during a typical year; actual energy costs may be substantially different.

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G. Building Performance Rating Method

General Information (§ G1)

In addition to being used for code compliance, Standard 90.1 is often used as a baseline for energy efficient and green building programs. An example of such a program is the U. S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program. In addition, many utilities have incentive programs that offer financial incentives for buildings that are more energy efficiency than code minimum.

The purpose of the ECB modeling rules and procedures described in Chapter 11 is to provide an overall building performance rating procedure that has more flexibility than the options in the individual chapters, but is still workable for code compliance. Since the rules are intended for minimum code compliance, they purposefully limit the ability to trade-off the minimum prescriptive requirements. However, this is less of a concern and more flexibility can be provided when the purpose of the procedure is to show that a building is significantly better than code minimum.

To respond to the need created by LEED and utility programs, ASHRAE added informative Appendix G with the 2004 update to Standard 90.1. The procedures in informative Appendix G are intended to provide more flexibility and to give credit for measures such as building orientation, natural ventilation, daylighting, and HVAC system design and selection.

While the purpose of Chapter 11 is to provide a flexible path to code compliance and to minimize gamesmanship for trade-offs, the purpose of informative Appendix G is to establish a baseline for the entire energy consumption of the building to be used to calculate percentage energy savings above this baseline. Appendix G gives credit for advanced design strategies and provides a standard procedure for rating the energy efficiency of the entire building.

The procedures in this chapter may be used with new buildings, additions to existing buildings and alternations to existing buildings. It may not be used, however, when the new or existing building has no mechanical system.

Terminology

In Chapter 11, the terms Energy Cost Budget (ECB) and Design Energy Cost (DEC) are used. A building complies with the performance standards if the DEC is less than or equal to the ECB. For overall building performance ratings, the terms *baseline building* performance and *proposed building* performance are used instead. The goal with energy rating systems is to show that the proposed building performance is better than the baseline building performance by some given margin, the performance goal.

The *rating authority* is the entity with responsibility for administering and enforcing the building performance rating. Appendix G gives considerable responsibility to the rating authority. It determines if documentation is adequate and it sets procedures for reviewing and accepting calculations. Another role for the rating authority is to determine the baseline for components of energy use that are not directly addressed by Standard 90.1. The most notable examples of this are receptacle or plug loads. Table G3.1-12 states that the receptacle loads for the proposed building and the baseline building shall be the same, except as specifically authorized by the rating authority.

How the Building Performance Rating Method is Different

There are a number of important differences between the ECB Method and the building performance rating method. In general, the ECB Method is very limiting and is focused on minimum code compliance, while the building performance rating method is more comprehensive, far more flexible (though the baseline may be more restrictive in some cases), and offers credit for a number of additional design measures and strategies.

The following are some of the key differences:

- A big difference between ECB and Appendix G is that for Appendix G "Vertical fenestration areas for new buildings and *additions* shall equal that in the *proposed building* or 40% of gross above-grade wall area, whichever is smaller". This is different in that ECB allows up to 50% based on the gross exterior wall area, which includes below grade walls.
- The building performance rating method includes the total energy consumption for all end uses. If neither Standard 90.1-2007 nor the rating authority set a baseline for a building component or characteristic, then the simulation model inputs for those characteristics shall be the same for both the proposed building and the baseline building (§ G1.2, § G3.9, § G4.5).
- Credit is offered for buildings that have more favorable building orientation and buildings with poor orientation are penalized.

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- Internal or exterior shades may be modeled and credited in the proposed building if they are automatically controlled.
- Credit is offered for occupancy sensors and programmable timers for lighting controls. These can be modeled by either modifying the lighting schedules or through power adjustment factors published in Appendix G.
- The rating authority may establish a baseline for plug loads or other unregulated loads and a method of crediting more efficient equipment (§ G3.9). Plug loads are to be included in the simulations and in the calculation of savings.
- Users are allowed to "substitute a thermodynamically similar component model" when the simulation tool can't explicitly model a building feature. This will help with certain innovative systems, but especially underfloor air distribution (UFAD) and thermal displacement ventilation (TDV).
- Photovoltaic (PV) systems may be modeled and credited in the calculations (Exception to G2.4).
- Credit is offered for energy efficient fan systems. With the ECB Method, fan power is the same for the standard design and the proposed design.
- Some credit is offered for natural ventilation for buildings that do not have cooling systems.
- More credit is offered for HVAC system selection. With the ECB Method, the budget system design depends in great part on the proposed system design, while with the building performance rating method, the baseline system type is determined mainly by the building type, number of floors, building total conditioned floor area, and heating source type, independently of the proposed design system.

Scope (§ G1.1)

The building performance rating method is intended for rating purposes only. It is not an acceptable means of complying with Standard 90.1-2007.

The building performance rating method may be used for new buildings as well as alterations and additions to existing buildings. The only exception is for new buildings, alternations, or additions that do not have a mechanical system. In this instance, the method may not be used.

Performance Rating (§ G1.2)

With the building performance rating method, a computer program is used to calculate the annual energy operating cost for both the proposed building and the baseline building. In the baseline building design, which is a variant of the proposed building, all mandatory and prescriptive requirements of the Standard are applied. In other words, the baseline building represents the building as if it were upgraded or downgraded to exactly comply with the Standard.

It is also necessary that the building be constructed to the efficiency levels modeled by the proposed design. This means that the efficiency of the individual components, the operation of the controls, and the overall design of the building must conform to the proposed design that was used to calculate the building performance rating. For this to happen, the building designers must accurately translate the energy assumptions used in the building performance rating calculations into the plans and specifications used to construct the building.

Mandatory Provisions (§ G1.2a)

In spite of the building performance rating margin between the proposed building and the baseline building, the proposed building shall meet the mandatory provisions of Standard 90.1. These are contained in § 5.4, § 6.4, § 7.4, § 8.4, and § 9.4 of the Standard. The mandatory provisions are not available for trade-off. The mandatory provisions are needed for many reasons.

- Some of the mandatory provisions, such as minimum motor efficiencies, are standard good practice and they should always be used.
- Some are difficult to accurately model in a computer simulation, such as subdivision of feeders, and so their trade-off value cannot be accurately determined.
- Some specify calculation methodologies needed to establish a fair basis for comparison of components, such as U-factor calculations.
- Some Mandatory Provisions are not intended for trade-offs, such as exterior lighting.

Calculating the Percentage Improvement

The building performance rating method process involves comparing the proposed building performance to the baseline building performance and calculating the margin in terms of the percent savings. Appendix G is designed to allow the rating to be based on either energy cost or energy consumption, at the direction of the Rating Authority. The comparison can be in the form of percent energy (Btu) savings or percent energy cost ($) savings.

The annual energy operating costs is calculated for both the proposed building and the baseline building in a consistent and comparable manner. In making the comparison, the following rules apply:

1. Both runs (computer simulations) shall use the same simulation program.
2. Both runs shall use the same climate data.
3. Both runs shall use the same purchased energy rates.

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4. Both runs shall use the same schedules of operation, except for adjustments needed to account for energy efficiency features.

These rules ensure a fair comparison between the two runs, without introducing extraneous differences. For instance, if the runs used different simulation programs, then some portion of the differences between the resulting energy costs would be due to differences in algorithms or calculation methodologies. These differences could skew the determination of which building features are allowable under the Standard.

Similarly, if two different purchased energy rates were used, part of the difference between the runs would be due to rate differences. While this may be real in particular applications, it would introduce variations in the efficiency requirements for the building that are inconsistent with the building performance rating method. Furthermore, due to the changeable nature of purchased energy rates, these differences may not last for the life of the building and so could skew the design of the building's energy-related features. Individual building owners or designers may choose to optimize their buildings to take advantage of special rates, but building performance ratings require that the same rate be used for both runs.

Once the annual energy cost is known for both the proposed building and the baseline building, the savings percentage is calculated using the following equation.

Percentage improvement = 100 x (Baseline building performance rating - Proposed building performance rating) / Baseline building performance rating

Include All Energy Components

Both the proposed building performance rating and the baseline building performance rating shall include all components of energy use, including receptacle loads, vertical transportation, garage ventilation, outdoor lighting, and process loads, such as refrigerated cabinets in supermarkets and clean rooms in laboratories. (Note that prior to the publication of Appendix G, rating programs did not always include all of the energy consumption in their comparison calculations.) Using less than the total energy consumption as a basis for comparison results in a higher percentage of energy savings. However, this is misleading to designers, building owners, and parties unaware of the basis for the comparison. They will hear percentage savings estimates and, unsurprisingly, construe this as applying to the total energy consumption or total energy cost of the building. As a result, confidence in energy savings estimates is undermined when the actual results are less than expected.

Since Standard 90.1 does not set a baseline for receptacle loads, elevators, etc., it is the intent of the 90.1 committee that these components be identical in both the baseline and the proposed design unless others (the rating authority in particular) develop an appropriate baseline for these components and develop a procedure for calculating the savings related to these components.

Some components are considered non-interactive, meaning they have no significant interactions with the heating and cooling energy components. So as to provide a comprehensive picture and increase ease of evaluation, it is recommended that these components be included in the overall hourly analysis. Each of these non-interactive components can be input as a separate zone that has no envelope loads or HVAC serving it. The non-interactive component is then simply input as a peak load with a schedule. This way the calculations are all done automatically.

While less desirable, when allowed by the rating authority, the energy use of these non-interactive components can be determined in a side calculation and added to the simulation results—as long as the effect is included in the utility rate and energy cost calculations.

Other components with interactive energy uses need to be directly considered in each zone of the energy simulation since they contribute heat or have other thermal interactions with the space heating and cooling system. Examples include receptacle loads, computer rooms, refrigerated casework, and other interior process loads that contribute heat or remove heat from the space and therefore affect space heating and cooling loads.

Your Mileage May Vary

It is important for users of the building performance rating method, as well as the owners of the proposed buildings, to understand the building performance rating method's intent and limitations. It is intended to provide a baseline for comparison of the estimated annual energy cost of the proposed building and the baseline building for purposes of a rating. It is not intended to provide an accurate prediction of actual energy consumption or costs for the building as it is actually built.

Although the energy analyst is expected to model energy use as closely as possible, there are many reasons why the actual building performance rating may differ from the predictions of the building performance rating method. These include:

- *Variations in occupancy*. The actual schedules of operation and occupancy may differ from those assumed in the building performance rating analysis.

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- *Variations in control and maintenance.* The building's energy systems may be controlled differently than assumed; the equipment may not be set up or maintained properly.
- *Variations in weather.* The simulation runs use weather data that may not match the actual weather conditions for a given year.
- *Changes in energy rates.* The electricity, gas, and other energy rates assumed in the calculations may change over time, resulting in higher or lower actual energy costs.
- *Precision of the simulation program.* Even the most sophisticated simulation programs approximate the actual energy flows and consumption in a building; further, the energy analyst will usually make simplifying assumptions, such as combining zones with similar conditions. Both can be sources of deviations in the predictions of energy cost and consumption.

The building performance rating method relies on the energy analyst and building designers to make reasonable assumptions for these factors, and the building performance rating results are expected to be reasonable predictions, especially since this is a comparative analysis and the proposed building and the baseline building use similar assumptions. However, it is clear from the points listed above, that even the best set of assumptions will likely lead to predictions that differ from actual building performance rating.

Trade-Off Limits (§ G1.3)

Savings may not be based on promises about the future or on building improvements made in the past. Savings must be based on "real time" as defined by the current scope of improvements and documented in the construction documents.

This does not mean, however, that the project may not be phased; it can. The test is that the construction documents include all phases so that the energy analyst and the rating authority can verify pre- and post-conditions. .

For building additions, the designer has the choice of including the existing building in the calculation of the percent energy savings or excluding it. If the existing building is excluded, then Table G3.1-2 applies and the following conditions must be met:

- Any work to improve the existing building must meet the prescriptive requirements and mandatory measures of Standard 90.1.
- The excluded portion for the existing building was served by a separate HVAC system.
- Heat transfer between the new building addition and the existing building must be minimal. If party walls separate the new and existing portions, space temperatures and schedules of operation on both sides of the boundary shall be similar.
- If both the existing and new construction areas are served by the same meter and the applicable utility rate includes ratchets, declining blocks, or other rate structures that are based on total energy consumption, the utility block or rate for the addition plus the existing building shall be used for the addition.

When the Building Performance Rating Method Can't Be Used

The building performance rating method may be used for just about any situation, but there are a few exceptions, as itemized below:

- *No Mechanical System.* When the proposed building has no mechanical system, then the HVAC system for the proposed design shall be equal to the baseline mechanical system which is

Example G-A—Using the Building Performance Rating Method

Q

I am making an addition to an existing building and last year, a new HVAC system was installed in the existing building. Can the baseline building include the pre-retrofit HVAC system and the proposed building include the improved system?

A

No. Only systems proposed to be modified in conjunction with the addition may be considered in the analysis. Other features improved in the past, or proposed to be improved in the future must be the same for both the proposed building and the baseline building.

Q

A proposed building has a 10,000 ft² parking lot, but the parking lot is not lighted. The Standard allows 0.15 W/ft² for parking lot lighting. Can the baseline building be modeled with a lighted parking lot, e.g. the proposed building is credited for not lighting its parking lot.

A

No. End uses that do not exist in the proposed building cannot be added to the baseline building.

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defined in terms of building size, number of floors, and building type (residential or nonresidential).

- *No Envelope Design*. New buildings or additions that do not have an envelope design cannot use the building performance rating method. The building envelope must first be designed so that the building performance rating calculations can account for its characteristics.

In the case of a newly conditioned space or a gut rehabilitation, where the existing envelope is not being changed or is not part of the permit, then the rules for alterations apply; the envelope would be modeled as-is and would be the same for both the proposed building and the baseline building.

Documentation Requirements (§ G1.4)

When the building performance rating calculations are submitted to the rating authority, the designers must include appropriate documentation. The documentation requirements are defined in § G1.4. The documentation should include the following:

- The annual energy cost of both the baseline building and the proposed building should be documented along with the percent savings.
- The energy-efficiency features in the proposed building that differ from the baseline building should be identified and clearly listed. It is necessary that the features be clearly described in the documentation, and that they be clearly indicated on the construction documents. For performance ratings, features such as favorable orientation, HVAC system selection, and reduced fan power may be listed since they are credited by the building performance rating system.
- Input and output reports from the computer simulation program should be provided. These reports should identify the components of energy use, which at a minimum should include: interior lighting, exterior lighting, service water heating energy (both electricity and gas), heating energy, cooling energy, fan energy, circulation pump energy, and other miscellaneous HVAC energy. All other energy end uses should be listed, even if Standard 90.1 does not provide a baseline. These numbers help to explain how the building is energy efficient and where the priorities for efficiency are found in the proposed building. In addition, the output reports must show the amount of time any loads are not met by the HVAC system for both the proposed design and the budget building design. If there is a substantial discrepancy between these two values, then the simulation models are not satisfactory (more detailed discussion of this issue follows).
- An explanation of any error messages produced by the simulation program. These messages indicate possible problems with the simulation models for the two designs, or they may simply indicate special conditions in the buildings. The burden is on the simulation modeler to explain which of these two conditions is indicated by each error message and to establish to the rating authority's satisfaction that the models adequately demonstrate compliance under the building performance rating method.

It would be highly desirable for the simulation engine to be coupled with software that automatically produces both the proposed building simulation and the baseline building simulation. Such software exists for use with some state and utility programs. Such software shells are also capable of producing the necessary documentation automatically and attending to other rules and procedures specified in Appendix G. At the time of this writing Appendix G has just been released and software shells as described above do not exist.

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Simulation General Requirements (§ G2)

Performance Calculations (§ G2.1)

Annual energy cost is calculated for both the proposed building and the baseline building using the same simulation program, the same weather data and at the same energy rates. These points are discussed in greater detail in the sections that follow.

Simulation Program (§ G2.2)

At the heart of the building performance rating method are calculations done by the simulation program. In order to make sure that these calculations are sufficiently accurate for the purposes of the Standard, Appendix G establishes a series of requirements.

The most basic requirement is that the simulation program be a computer-based program designed to analyze energy consumption in buildings, and that it have the capability to model the performance of the proposed building's energy features. Building performance rating calculations are too complex for hand calculations, and there are many computer programs available that have the needed capabilities and are in widespread use. Examples include DOE-2, BLAST, and EnergyPlus, which were developed largely with public funds, and which are available to users in both public and private sector versions.

Several other proprietary programs also exist that have the minimum capabilities required by Appendix G. A listing of simulation tools that may be suitable for the building performance rating method can be found on the U.S. Department of Energy's web site at http://www.eere.doe.gov/buildings/tools_directory/.

The simulation program shall be tested according to ANSI/ASHRAE Standard 140-2004 and the results shall be made available by the software provider.

Minimum Modeling Capabilities (§ G2.2.1)

Section G2.2.1 specifies a minimum set of modeling capabilities for building performance rating method simulation programs. These requirements are broadly defined to allow all capable programs to be considered for approval by the rating authority, while eliminating programs that would not be able to adequately account for the energy performance of important building features. These minimum capabilities are:

- *Minimum hours per year*. Programs must be able to model energy flows on an hourly basis for the full 8,760 hours during a year. Programs that use representative days for the different months and seasons are not permitted.
- *Hourly variations*. Building loads and system operations vary hour-by-hour (or even for shorter durations), and their interactions have a great influence on building energy performance. Approved programs must have the capability to model hourly variations—and to establish separate schedules of operation for each day of the week and for holidays—for occupancy, lighting power, miscellaneous equipment power, thermostat set points, and HVAC system operation.
- *Thermal mass effects*. A building's ability to absorb and hold heat varies with its type of construction and with its system and ventilation characteristics. Mass may be located in exterior walls or other surfaces or interior to the space. Thermal mass affects the timing and magnitude of thermal loads handled by the HVAC system. Simulation programs must be able to model these thermal mass effects.
- *Number of thermal zones*. All but the simplest buildings have multiple thermal zones, with each zone experiencing different load characteristics. Approved programs must be able to model at least 10 thermal zones; many simulation programs can handle a far greater number.
- *Equipment capacity and efficiency correction curves*. Mechanical equipment seldom operates continuously at full-load operating conditions or at the outdoor and indoor rating conditions, so the simulation program shall have the capability to model equipment under a variety of climate and part-load conditions.
- *Economizers*. Economizer cooling is an important efficiency measure and is incorporated in the baseline building. Approved programs must have the capability to model air side economizers with integrated control. Integrated control means that the economizer model must be able to credit economizer cooling for meeting the cooling load even when it must work in tandem with the mechanical cooling system to do so.
- *Baseline building design characteristics*. In addition to the general capabilities described above, simulation programs must have the capabilities to model the baseline building design, as specified in § G3. This is to ensure that the program can

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properly calculate the baseline building performance rating. Without this, percent savings calculations are not possible.

Proposed Building and Baseline Building Performance (§ G2.2.2)
The simulation program shall have the capability to apply energy rates and calculate the proposed building and baseline building performance, as expressed in annual energy costs. Alternatively, the simulation program may produce hourly reports of energy use for each of the components (electricity, gas oil, propane, purchased steam, etc.) and the building performance rating for the proposed building and the baseline building may be calculated in a post-processing step.

Design Load Calculations (§ G2.2.3)
The simulation program must be capable of performing design load calculations to determine required HVAC equipment capacities and air and water flow rates for both the proposed building and the baseline building. Calculations shall be based on generally accepted engineering standards.

Sizing calculations are needed to ensure that equipment in the baseline building is sized. For the baseline building performance rating, equipment shall be sized according to § G3.1.2.2, which over sizes cooling equipment by 15% and heating equipment by 25%. The intent is that one combined safety factor is applied. A safety factor should not be applied separately to airflows, coils, pumps, and central plant equipment.

Climate Data (§ G2.3)

Climate data must be approved by the rating authority. The climate data must provide representative hourly values for all the relevant parameters needed by the simulation program, such as temperature and humidity. In addition, data on solar energy, cloudiness, wind, etc., are often used by the programs.

Because the simulations are meant to represent the building's long-term energy performance, it's important that the climate data represent both average and design conditions. The average conditions alone are not sufficient because equipment-sizing calculations need data on design weather conditions.

Equipment sizing calculations may be performed using the hourly data or by using separate design data. When separate design data is used it must be developed using 99.6% heating design temperatures and 1% dry-bulb and 1% wet-bulb cooling design temperatures (see § G3.1.2.2.1).

There is frequently a need to apply engineering judgment in selecting climate data because weather stations having full data collection capabilities are not always located close to the proposed building site. In this case, the closest available weather station data should be used. Closest may not always mean geographic proximity, however. Major terrain features, such as elevation or proximity to marine conditions (the seashore), could affect the choice of the climate data set. The objective is to best approximate the weather conditions that will be experienced at the building site.

Energy Costs (§ G2.4)

In addition to calculating energy use in the building, the simulation program must be able to calculate the energy cost, based on purchased energy rates. This may be done either directly within the program, or as a side calculation. If done as a side calculation, the program must be capable of producing hourly reports of energy use by energy source, to which the approved purchased energy rates can be applied. This capability must be available for both the baseline building and the proposed building.

The energy analyst has some latitude to choose between different rates or rate structures that may be available for the proposed building, but the choice should best represent the purchased energy rates that will apply to the building over its lifetime.

There is a special case for calculating the energy cost for proposed buildings that have on-site renewable energy sources or site-recovered energy. For example, a building may have a solar thermal array, photovoltaic panels, or access to a geothermal energy source. Or a building with substantial refrigeration loads may recover heat from the condenser to meet service water heating loads. If the proposed building has either renewable or recovered energy, this energy is considered free energy by the building performance rating method, and that energy is not included in the proposed building performance rating.

The baseline building does not have on-site renewable energy sources or heat recovery, except as required by § G3.1.2.10 (exhaust air energy recovery) or Table G3.1-11b (condenser heat recovery for hot water). For the baseline building, the loads which are met by renewable or recovered energy in the proposed

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building are considered to be served by the backup energy source.

For example, where recovered energy is used to heat water (and this is not required by Table G3.1-11b), then the backup water heater would be assumed to supply all the hot water for the baseline building, and that cost would be part of the baseline building performance rating. If no backup energy source is specified for the proposed building, then the source is assumed to be electricity in the proposed building design, and the approved purchased electricity rates are used to calculate that component of the baseline building performance rating.

This section of the User's Manual describes how the proposed building is created for the building performance rating method.

Exceptional Calculation Methods (§ G2.5)

As newer technologies become available, there may be cases where none of the existing simulation programs can adequately model the energy performance of these technologies. The Standard allows the rating authority the discretion to approve an exceptional calculation method for use with the rating method. The nature of the exceptional method is open-ended, but the burden is on the applicant to demonstrate that the method is reasonable, accurate, well founded, and not in contradiction with the rules of the building performance rating method.

The applicant must describe the theoretical basis for the exceptional method and must provide empirical evidence that the method accurately represents the energy performance of the design, material, or device. This documentation must also show that the method and its results.

1. Do not change the simulation program input parameters that are constrained by the building performance rating method or any other rules of the rating authority.
2. Provide adequate documentation for verification, including the assumptions and inputs to the method and the results and outputs of the method. The results must produce clear and consistent reporting of the required equipment and system features to enable verification both on the construction documents and during field inspections. The documentation should also be consistent with the other documentation requirements established by the rating authority.
3. Provide instructions for the exceptional method, so that other users may apply it consistently and fairly in future rating method applications. Once approved, the exceptional calculation method will become, in effect, an amendment to the rating method. An example of a change in the simulation program might be a new algorithm for ground source heat exchangers or a credit for occupancy sensors. The rating authority is not discouraged from approving exceptional methods, but it should exercise judgment and care in approving them to ensure that they do not grant undue credit.

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Calculation of the Proposed and Baseline Building Performance (§ G3)

Building Performance Calculations (§ G3.1)

The proposed building energy use or cost is compared to the baseline building energy use or cost to determine the building performance rating. The energy cost of the proposed building and the baseline building are calculated as separate runs by an acceptable simulation program using the rules spelled out in Appendix G and this chapter.

The most important thing for a designer to understand about the building performance rating method is how the two simulation runs differ from each other; it is these differences that determine the margin of improvement between the proposed building and the baseline building. Many, if not most, of the inputs to the two simulation runs are identical. These identical building features and operational characteristics are "energy neutral," i.e., they produce no energy credits or debits that could affect the energy performance rating. The features that are different may result in savings or increases in energy cost, and so these differences are the ones that determine the building performance rating margin.

This section discusses how energy costs are calculated for both the baseline building and the proposed building. The general rule for the baseline building run is that all inputs must be identical to the proposed design run, except for those features that are allowed to differ. This ensures that the two runs are comparable and that credit is given only for those features of the proposed building that will produce reliable energy savings over the life of the building.

Some ways of reducing unnecessary energy waste, which may be perfectly valid in the completed building, are not credited under the building performance rating method. For example, building managers might operate a building at very low energy levels during off-hours when it is unoccupied. A designer may wish to take a credit for these savings by assuming more off-hour energy use in the baseline building than in the proposed building. These savings, however, may or may not actually occur and they are certainly less reliable than the savings from improved insulation or a more efficient lighting system. Under the building performance rating method, these latter improvements would be credited, but the hypothetical operational changes would not. Credits are available only when explicitly allowed by the building performance rating method, including all improvements in the proposed building beyond the prescriptive sections of the standard.

For new buildings, the basic concept is that the baseline building be the same as the proposed building, except that each of the components is assumed to just meet the applicable mandatory provisions and the applicable prescriptive requirements of the Standard, as further defined in Appendix G and this chapter. In some cases Appendix G defines a baseline characteristic that varies somewhat from the prescriptive (e.g. economizer control) standard.

There is a distinction between the mandatory provisions and the prescriptive requirements. Section G1.2 states that the proposed building must always comply with the mandatory provisions. The mandatory provisions can never be traded off. However, credit can be taken for improvement over the minimum mandatory provisions (for example, mechanical equipment efficiency). The prescriptive requirements, on the other hand, become the criteria in the baseline building, but these are allowed to be

Example G-B—Applying Thermal Zones before Duct Design Completion

Q

A permit has been applied for before the duct design has been completed. The interior partition walls are 25 ft from the exterior walls. How would the design and budget building thermal zones be applied?

A

When the HVAC zones have yet to be designed, the perimeter thermal zones in the simulation will extend inward 15 ft from the perimeter wall regardless of partitions or interior walls. Figure G-D illustrates how the thermal zones and architectural zoning of the building differ.

Note that this 15 ft rule only applies to HVAC systems that have yet to be designed. When the HVAC zoning has been designed, the thermal zones in both the proposed building and baseline building should reflect the actual zoning.

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traded off (for example, window SHGC). Of course, trading off any of the prescriptive measures means that even greater improvements will need to be made elsewhere to achieve a certain percentage energy savings.

If the energy analyst chooses to use the addition plus existing approach, new system components in the existing building are assumed to meet the prescriptive requirements, while unchanged components are modeled at their existing levels of energy performance.

The following sections describe how the proposed and baseline buildings are derived for each of the major building systems.

Design Model (Table G3.1-1)

The proposed building performance rating is calculated by the simulation program based on the proposed design, which is documented on the construction documents. For most new buildings, this is a straightforward exercise in modeling the building as it was designed, using good engineering judgment and the capabilities of the simulation program. All the building features shown in the design documents, including building size and shape, building envelope components and assemblies, lighting, water heating, and mechanical system equipment and controls, must be accounted for. The rules for calculating the proposed building performance rating in § G3 deal primarily with special circumstances and exceptions.

With the ECB Method it is only necessary to model regulated energy uses; however, with the building performance rating method, it is necessary to model all end-use load components within and associated with the building, including but not limited to, exhaust fans (also included in ECB calculations), parking garage ventilation fans, snow-melt and freeze-protection equipment, parking lot lighting, facade lighting, swimming pool heaters and pumps, elevators and escalators, commercial refrigeration, and cooking. Where the simulation program does not specifically model the functionality of the installed system, spreadsheets or other documentation of the assumptions shall be used to generate the power demand and operating schedule of the systems.

Additions and Alterations (Table G3.1-2)

For building additions, the designer has the choice of including the existing building in the calculation of the percent energy savings or excluding it. If the existing building is excluded, then the following conditions must be met.

- If there is any new work covered by the Standard that is in a part of the existing building that will be excluded from the proposed design modeling, then those parts must comply with the Standard's applicable mandatory and prescriptive requirements.
- The excluded parts of the existing building must be served by HVAC systems that are completely independent of the systems or building components being modeled for the proposed building performance rating.
- There should not be any significant energy flows between the excluded parts of the building and the modeled parts. In other words, the design space temperature, HVAC system operating setpoints, and operating and occupancy schedules on both sides of the boundary between the included and excluded parts must be the same. If the excluded portion of the building was a refrigerated warehouse and the included portion was an office, this condition would not be met, because there would be significant energy flows between them.
- If the included and excluded parts of the building share the same utility meter, and if there is a declining block or similar utility rate used for the analysis, then the energy cost analysis must be based on the full energy use block for the building plus addition. This may be done either by modeling both the existing portion of the building plus the addition served by the utility meter, or by making an appropriate adjustment in the energy cost calculation to account for the difference.

Space Use Classifications (Table G3.1-3)

A key task in modeling the proposed design is assigning space use classifications to different areas of the building. These classifications are used to determine the lighting power for the baseline building and to differentiate areas within the building that may have different operating schedules and characteristics (thermostat settings, ventilation rates, etc.).

The choice of space use classifications is taken from one of the two lighting tables in the Standard: either Table 9.5.1 (the building area method) or Table 9.6.1 (the space-by-space method). The designer may choose either classification scheme but may not mix the schemes by using one for part of the building and the other for the rest of the building. The reasons for choosing one method over the other are discussed more fully in Chapter 9 of this Manual.

"Building," in this context, refers to the space encompassed on the construction documents, which may be less than the complete building.

If the building area method is used for a mixed-use facility, the building may be subdivided into the different areas that correspond to the building types listed in Table 9.5.1. The secondary support areas associated with each of these major

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building types would be included in each building type. For example, if a building included both office and retail areas, the corridors, and restrooms associated with the office occupancy would be included in the office area, and the storage and dressing room areas associated with the sales floor would be included in the retail area.

Schedules (Table G3.1-4)

The operating and occupancy schedules for the building and its systems have a large impact on the overall energy cost. The Appendix G allows designers, with the approval of the rating authority, to select reasonable or typical schedules for the building. In selecting the schedules, it is prudent to consider the likely long-term operation of the building. For example, if a new school will initially operate on a traditional schedule, but the school district has a policy of shifting its schools over to year-round operation, then it would be prudent to apply a year-round schedule in the modeling.

The selected schedules should likewise not intentionally misrepresent the operation of the building. If a grocery store chain keeps its stores open 24 hours a day, it would be inappropriate to use a 12-hour-a-day operating schedule in the modeling.

When appropriate, separate schedules should be used for weekday, Saturday, Sunday, and holiday schedules for each of the following:

- Occupancy;
- Lighting;
- Miscellaneous equipment power;
- Thermostat setpoints;
- HVAC system operation, including system availability, fans, off-hour operation, etc;
- Any other significant loads or equipment that could affect trade-off calculations including garage ventilation, outdoor lighting, etc.

Where the actual schedules are not known, you may consult the values in Table G-E through Table G-N for guidance.

Occupancy schedules are used in a simulation to define a number of building conditions and loads. Schedules can include information such as the occupancy level of a building, internal temperatures to be maintained and what percentage of equipment loads are "on" at a given moment. Schedules can vary significantly from building to building and tenant to tenant. Over the years a number of schedules have been defined using a variety of sources. The schedules given in Table G-E through Table G-N are based on ASHRAE *Standard 90.1-1989*, the last year schedules were included in this consensus document. They are reproduced in this chapter as an example of typical input data.

While engineers are often concerned with sizing equipment for the worst case load scenario, average conditions should be used for energy simulations. For example: electrical wiring is required to be sized for 3 watts per square foot of lighting load in a building. In actual practice lighting is typically half or less of that value, with many of today's designs coming in at less than one watt per square foot. In addition, not all lighting is typically turned on at a given moment, so that the real load is only a fraction of what is used for wiring design. The same is true for building occupancy. The occupancy used for calculating emergency exiting requirements is considerable higher than the typical occupancy of the space. Be sure to review all schedules and peak loads against realistic expectations before using them in the simulation to make sure proper load levels are being included.

The schedules for the proposed building and the baseline building shall be identical, except as permitted by the rating authority. With the proposed building method (but not the ECB Method) it is possible to make changes or adjustments to the schedule to credit lighting controls, natural ventilation, demand control ventilation, and measures that reduce service water heating loads.

Schedules for HVAC fans that provide outdoor air for ventilation must operate the fans continuously when the space is occupied. The only two exception to this requirement are: 1) when the proposed building does not have a cooling system and the default system of the baseline building is used for the proposed building, the system fan should be cycled on and off to meet heating and cooling loads during all hours; 2) HVAC fans shall remain on during occupied and unoccupied hours in spaces that have health and safety mandated minimum ventilation requirements during unoccupied hours.

Building Envelope (Table G3.1-5)

The basic rule for modeling the building envelope in the proposed building performance rating calculations is to use the design shown on the final architectural drawings, including building shape, dimensions, surface orientations, opaque construction assemblies, glazing assemblies, etc. In some cases, the building envelope may already exist, as in the case of newly conditioned space or a tenant build-out of a shell building; in these cases, the existing building envelope is modeled for the proposed building and these same conditions are assumed for the baseline building.

Any simulation program necessarily relies on a somewhat simplified description of the building envelope. It is

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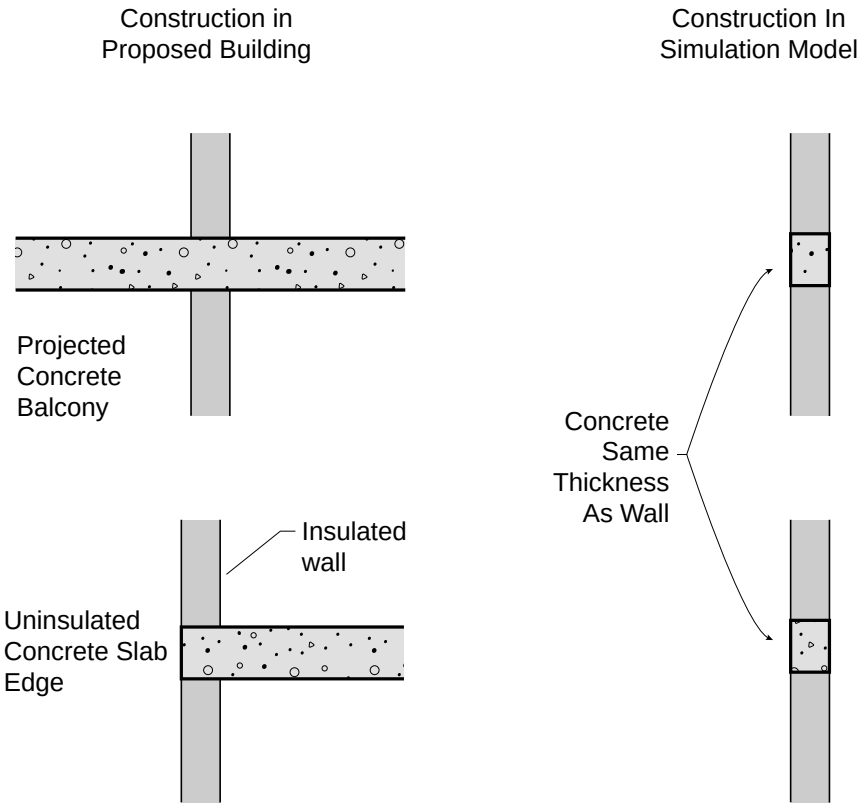

Figure G-A—Modeling Uninsulated Wall Conditions

usually too time consuming and difficult to explicitly detail every minor variation in the envelope design, and if good engineering judgment is applied, these simplifications won't result in a significant decline in accuracy.

The following issues are explicitly addressed by the building performance rating method.

Uninsulated Assemblies

All uninsulated assemblies shall be explicitly modeled. Examples include projecting balconies, perimeter edges of intermediate floor slabs, concrete floor beams over parking garages. All uninsulated assemblies shall be separately modeled using a separate description of each of these assemblies within the energy simulation model, or the area-weighted average U-factor based on separate calculation of the U-factor for each of these assemblies. The latter approach may only be used for assemblies with similar thermal mass.

These uninsulated components perform significantly differently than insulated components and can represent significant energy losses. In addition, these uninsulated components are often concrete and have a thermal mass that is quite different from the light mass steel stud walls that are used as infill between the insulated components.

Projecting balconies and perimeter edges of intermediate floor slabs are considered part of the exterior wall area. While there may be more sophisticated methods of modeling these uninsulated assemblies, it is acceptable to model them as having the depth of the exterior walls they penetrate.

For example, if the wall between the intermediate floor slabs has a total depth of 8 inches, then these assemblies can be modeled as being 8 inches thick. If the concrete slab that forms the projecting balcony or intermediate floor slab for a particular floor is 9 inches thick, then this section of the wall would be modeled in the proposed design as a 9 inch high uninsulated concrete wall that is 8 inches thick.

For the baseline building, this portion of the exterior wall would be considered a steel-framed wall complying with the prescriptive requirements for the appropriate climate zone. See Figure G-A.

Lateral heat transfer may be ignored in the simulation, e.g. wall constructions can be modeled as if heat from one section does not pass to the other.

This approach is also generally applicable to the edges of concrete floor slabs that separate parking garages from heated spaces above. Specifically, if the concrete floor slab is insulated below the slab (or not insulated at all), then the edges of the floor slab are considered part of the wall area and the bottom of the slab is considered part of the floor area. The only exception would be if the concrete slab floor was insulated above the slab. In this case, the edge of the floor slab would be beyond the conditioned area of the building and thus would not need to be insulated.

Except as noted in the previous paragraph, concrete floor beams over parking garages are considered part of the exterior floor area. Ideally, these beams would be completely wrapped with insulation. However, if the floor between the beams is insulated, but the beams themselves are not insulated, then the

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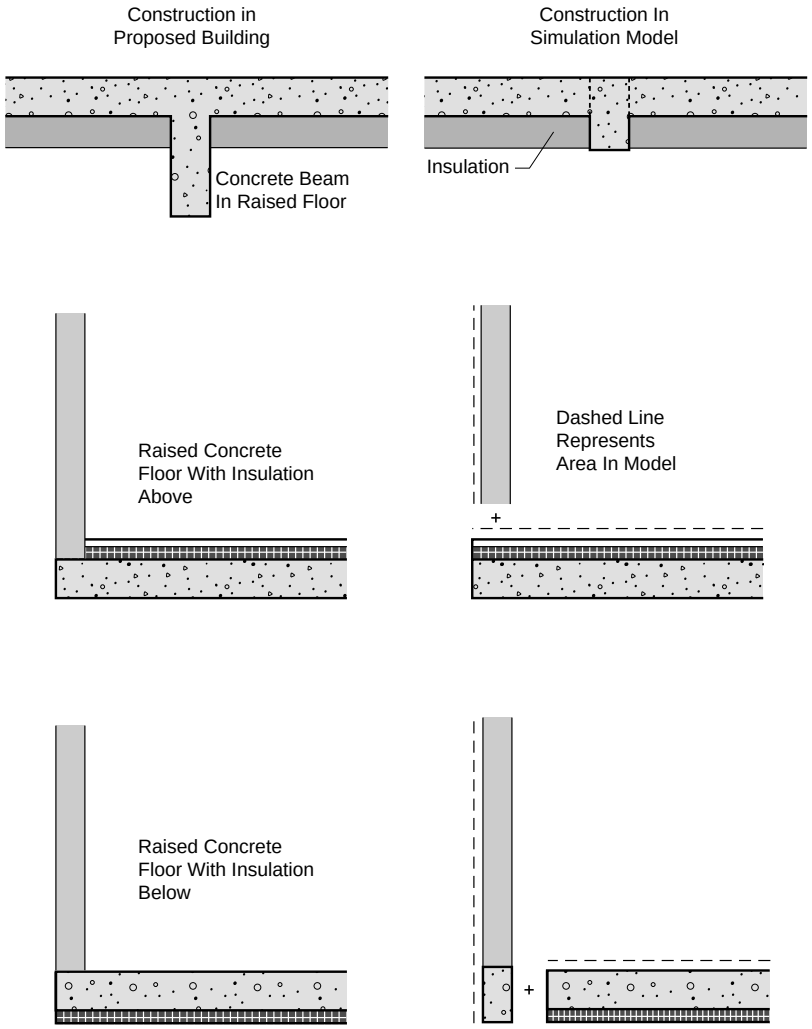

Figure G-B—Modeling Uninsulated Floor Conditions

concrete beams are uninsulated components that need to be modeled separately.

Again, while there may be more sophisticated methods of modeling these uninsulated assemblies, it is acceptable to model them as having the thickness of the exterior floors they penetrate. For example, if the floor between the floor beams has a total thickness of 14 inches (including 1 inch of flooring material, a 9 inch floor slab, and 4 inches of rigid insulation), then these floor beam assemblies can be modeled as being 14 inches thick. If the concrete floor beam is 24 inches wide, then this section of the floor would be modeled in the proposed design as a 24 inch wide uninsulated concrete floor that is 14 inches thick. See Figure G-C.

For the baseline building, the whole exterior floor would be considered a steel-joist floor complying with the prescriptive requirements for the appropriate climate zone.

Note that the area of multiple uninsulated beams within the same zone can be combined for modeling purposes. (Also, see the discussion of Thermal Blocks in Tables G3.1-7 through G3.1-9 for information on grouping HVAC zones into thermal blocks).

Minor Insulated Assemblies

Frequently, there will be small areas on the building envelope that have unique thermal characteristics. Provided that these assemblies are insulated, the method allows any envelope assembly that covers less than 5% of the total area of a given assembly type (e.g., exterior walls or roofs) to be added to an adjacent assembly of the same type with the same orientation and the same thermal properties. This is not intended, however to allow framing members in walls to be ignored just because they have an area less than 5%.

Clearly, a small portion of a steel frame wall insulated to R-15 could be combined with the predominant assembly where that wall is a steel frame wall with R-21 insulation. To model this overall steel frame wall correctly, an area-weighted average U-factor should be calculated that includes both the R-15 and the R-21 areas.

However, note that for example, if there is an exterior wall constructed of load-bearing masonry, with small wood-framed infill areas, the infill areas cannot be treated as if the entire wall is of masonry because the walls do not have the same thermal properties.

Note that the gross wall area is unchanged, and no areas are left out of the model. Despite this limited allowance to combine same type assemblies, it is still preferable and more accurate to model these minor assemblies. Modeling these assemblies separately also simplifies review and evaluations, as each assembly types

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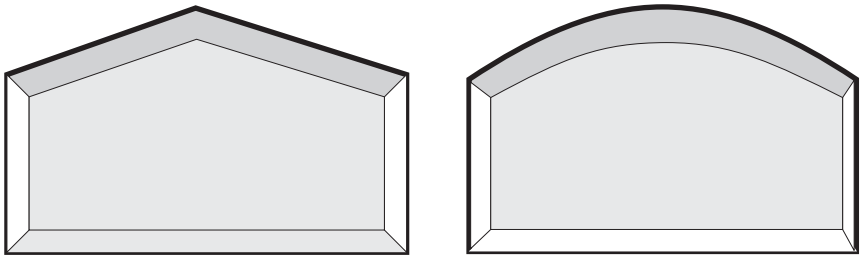

Figure G-C—Simplifying Building Geometry for Energy Simulation

can be directly traced back to a particular section drawing.

Different Tilt or Azimuth
This exception, primarily intended to address curved surfaces, specifies the minimum number of orientations into which these surfaces must be split up. The Standard allows similarly oriented surfaces to be grouped under a single tilt or azimuth, provided they are of similar construction and provided that the tilt or azimuth of the surfaces are within 45° of each other. They may be grouped as a single surface or a multiplier may be used. The complex curved building plan shown on the left side of Figure G-D may be replaced with the much simpler pentagonal plan on the right with little loss in building simulation accuracy.

Reflective Roofs
By default, exterior roof surfaces, other than those with ventilated attics, must be modeled assuming a surface reflectance value of 0.30. When a proposed design calls for a reflective roof surface, however, the model may assume a long-term average reflectance of 0.45, which credits the lower heat absorption of the reflective surface and makes a conservative allowance for degradation of the reflectivity over its lifetime. In order to qualify for this credit, the reflectance of the proposed design roof must exceed 0.70, and its emittance must exceed 0.75. Further, the reflectance and emittance values must be based on tests done in accordance with the following ASTM test standards: reflectance values shall be based on testing in accordance with ASTM E903, ASTM E1175, or ASTM E1918, and the emittance values shall be based on testing in accordance with ASTM C835, ASTM C1371, or ASTM E408.

Fenestration Shading Devices
Manual fenestration shading devices such as blinds or shades shall not be modeled. Automatically controlled fenestration shades or blinds may be modeled. Permanent shading devices such as fins, overhangs and light shelves may be modeled.

Baseline Building Envelope
The budget building design has the same physical shape characteristics as the proposed design, including:

- Same conditioned floor area;
- Same roof, wall, glazing (up to the maximum allowable window-to-wall-ratio [WWR]), and other surface areas;
- Same surface tilts and orientations.

For the building performance rating calculations, the characteristics of these envelope components are set to the prescriptive values specified in Table G3.1-5. There are a few exceptions to these basic rules as described below.

Baseline Building Orientation
The baseline building has the same surfaces area and orientations as the proposed building, but in order to credit favorable building orientation and penalize poor building orientation, the baseline building is modeled in four orientations. The baseline building performance rating is taken as the average of the four results.

This is a significant difference between the building performance rating procedures and the ECB procedures. With the ECB procedures, if a designer is careful to properly orient windows for minimum solar gains, the energy budget buildings assumes the same orientation and there is no credit.

Many components of energy use will not change as the building orientation changes. These components include lighting (unless daylighting is explicitly modeled), plug loads, miscellaneous equipment, vertical transportation, exterior lighting, and water heating energy. However, HVAC energy can be quite sensitive to building orientation. Components of HVAC energy include heating, cooling, fans, pumps, and other equipment.

If the proposed building has a shape that shades itself during portions of the day, for instance a donut or "L" shaped building, the self-shading is ignored in the baseline building. Such features are credited to the proposed building when

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they are a benefit. Shading of the building by surrounding structures and topography should be modeled identically in both the proposed and baseline buildings.

Baseline Building Opaque Assemblies
The baseline building is assumed to be steel framed no matter what the construction of the proposed building. If the proposed building has thermal mass in the exterior construction and this is a benefit in a particular climate, then the mass is credited in the building performance rating method. Likewise, if the proposed building is wood-framed, there would be a benefit associated with fewer thermal breaks and a lower U-factor for the same amount of insulation.

The wall, roof, floor, slab and door constructions in the baseline building shall comply with the applicable prescriptive requirements for the following classes of construction:

- Roofs, insulation entirely above deck;
- Above-grade walls, steel-framed;
- Floors, steel-joist;
- Opaque door types shall match the proposed design and conform to the U-factor requirements from the same tables;
- Slab-on-grade floors shall match the F-factor for unheated slabs from the appropriate climate specific table.

With the ECB Method, the class of construction in the budget building is the same as the class of construction in the proposed building, while with the building performance rating method, the baseline building always is steel construction and a roof with insulation entirely above the deck.

For alterations to existing buildings, the baseline building shall conform to § 4.1.1.2 through § 4.1.1.4 of the Standard.

Baseline Building Vertical Fenestration
Fenestration requirements apply to four areas:

Overhangs and Other Shading Projections
The baseline building design is assumed to have glazing that is flush with the outside surface of the exterior wall surface. This means that the building performance rating method gives shading credit for window recesses, overhangs, side fins, or other permanent shading devices that reduce solar gains on the glazing, including self shading from the building itself. The baseline building is also assumed to have no interior shading devices, such as mini-blinds or curtains. However, the proposed building may be modeled with interior or exterior shading devices as long as they are automatically controlled.

Fenestration Area
The fenestration area in the baseline building shall be equal to the fenestration area in the proposed building or 40% of the gross above-grade exterior wall, whichever is less. If it is necessary to reduce window area in the baseline building, then corresponding increases are made in the opaque walls such that the gross exterior wall area is unchanged between the proposed building and the baseline building.

Fenestration area in the baseline building shall be distributed on each face of the building and in each thermal block in the same manner as the proposed building.

While the prescriptive envelope requirements provide an exception for street-level, street-side vertical fenestration (e.g., store display windows), the building performance rating method does not. Window area in the baseline building is always determined as described above.

Example G-C—Fenestration

Q

I have designed a school according to the Collaborative for High Performance Schools (CHPS) guidelines with the majority of windows facing either south or north. Through careful site planning and building design, I have avoided windows facing east and west. The south-facing windows are also shaded by properly sized overhangs. Will these efforts be rewarded when I use the building performance rating method?

A

Yes. With the building performance method, the baseline building has the same shape and orientation as the proposed design, but the baseline building is modeled four times. After the initial simulation, it is rotated 90, 180 and 270 degrees and the baseline building performance is taken as the average of these results. The south-facing overhangs are also credited, since the baseline building is modeled with no exterior shading devices and the windows flush with the outside surface of the exterior walls. Furthermore, if the building is configured in such a way that it is capable of shading itself (e.g. "L" or "U" shaped), this self shading is not modeled in the baseline building.

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U-Factors

The fenestration U-factor in the baseline building is set to the minimum required for the climate and for the WWR of the baseline building, as specified in Tables 5.5-1 through 5.5-8 of the Standard. The minimum U-factor is a function of the baseline building glazing percentage, which is taken from the proposed design or 40% of the gross above-grade exterior wall, which ever is smaller.

SHGC

The budget building design's fenestration solar heat gain coefficient is set to the maximum required for the climate. The prescriptive standards give SHGC criteria for all orientations and provide an exception for north facing fenestration. The exception is not used for the baseline building; the criteria for all orientations are used for all orientations. The maximum SHGC is a function of the glazing percentage, which is taken from the proposed design or 40% of the gross above-grade exterior wall, which ever is less.

Baseline Building Skylights and Glazed Smoke Vents

Skylights in the baseline building are defined in a similar manner as vertical fenestration. If total skylight area is less than or equal to 5% of the gross roof area, then area and configuration in the baseline building is identical to the proposed building. If the proposed building has skylights that exceed 5% of the gross roof area, then each skylight in the baseline building is reduced in size such that the total skylight area in the baseline building is exactly 5% of the roof area.

Orientation and placement of skylights in the baseline building is identical to the proposed building. The only difference is that they may be smaller if the skylight area in the proposed building exceeds 5%.

Example G-D—Baseline Building Model, Building Envelope

Q

A proposed office building in New York City has a total exterior wall area of 400,000 ft² and a 60% window-to-wall ratio (see wall and window characteristics in the table below). The building entrance doors are glass and are included in the window area. There are 120 ft² of opaque swinging fire exit doors. How is the baseline building modeled?

A

When the window area in the design building exceeds 40%, the window area in the budget building is set to 40% of the total exterior wall area and the opaque wall type for the baseline building replaces any window area that is removed. The opaque door area does not change. Thus the total wall area (opaque wall + opaque door + window area) is the same for both baseline building and proposed building. The baseline building has each window (including glass doors) area reduced proportionally by a factor of 67% (40%/60%=67%) from the proposed building. The baseline building uses the SHGC values for all orientations (the north facing exception is not used with Appendix G). Now York city belongs to climate zone 4A.

	Proposed Building	Baseline Building	Baseline Envelope Properties
Total exterior wall area	400,000 ft²	400,000 ft²	
WWR	60%	40%	Maximum WWR
Window area	240,000 ft²	160,000 ft²	
Window type	Fixed	Fixed	U = 0.57 Btu/h·ft²·°F
Fraction windows north	40%	26.67%	
North window area	96,000 ft²	64,000 ft²	SHGC = 0.39
East window area	48,000 ft²	32,000 ft²	SHGC = 0.39
South window area	48,000 ft²	32,000 ft²	SHGC = 0.39
West window area	48,000 ft²	32,000 ft²	SHGC = 0.39
Opaque door area	120 ft²	120 ft²	U = 0.7 Btu/h·ft²·°F
Opaque wall area	159,880 ft²	239,880 ft²	
Wall type	Concrete	Steel frame	U= 0.124 Btu/h·ft²·°F

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In terms of thermal and solar performance, fenestration in the baseline building shall have a U-factor and SHGC meeting the prescriptive requirements for the appropriate climate zone and condition. Separate prescriptive criteria are provided for three classes of skylights: plastic skylights (which are always assumed to be positioned on a curb), glass skylights on a curb, and skylights with no curb. For skylights, the curb is important because the U-factor considers heat losses through the curb as well as the glazing and the frame.

The fenestration U-factor and SHGC for the baseline building is based on the skylight class, which is the same for both the proposed building and the baseline building. If the proposed building has plastic skylights on a curb, then so does the baseline building. Likewise, if the proposed building has skylights on no curb, so does the baseline building.

Cool Roofs

The reflectivity of roof surfaces affects solar heat gains and cooling loads. The building performance rating method allows credit for high reflectivity roof surfaces, provided they meet the requirements discussed above for roofs in the proposed building, by requiring the baseline building design reflectivity to be set at 0.3 (30%) for all roofs.

Mandatory Provisions

For the building envelope, the mandatory provisions are in §5.4. Some mandatory provisions worth highlighting follow.

- The roof insulation shall not be installed on a suspended ceiling with removable ceiling panels (§ 5.8.1.8).
- Fenestrations ratings must be per NFRC unless one of the default values is used (§ 5.8.2.1).
- Vestibules must be installed unless the project qualifies for one of the exemptions (§ 5.4.3.4).

Again, remember that these mandatory provisions are requirements that cannot be traded off. Any rated building must comply with these requirements.

Existing Building Envelope Conditions

When the performance rating is determined for an addition with consideration of improvements to the existing building, the baseline building envelope shall represent existing conditions prior to construction.

Lighting (Table G3.1-6)

Proposed Building

Lighting systems are a very important component of energy use for most nonresidential building types.

The building performance rating method builds upon the prescriptive lighting path in § 9.5 and § 9.6. Theatrical and other specialized lighting are exempt from the Standard but generate internal gains nonetheless. This exempt lighting must be modeled in both the proposed and baseline buildings in addition to the non-exempt lighting. It is the same, however between the proposed building and the baseline building.

If construction documents are complete, the proposed building lighting system power is modeled as shown on the design documents. If a lighting system already exists, then the proposed design is based on actual lighting power of the existing system and this power is also used in the baseline building.

In the special case where no lighting system or design exists, as in a shell building where the lighting will be installed by a future tenant, then a default lighting power must be assumed, based on the Building Area Method for the appropriate building type. If no building type is known, then an office building is assumed.

Lighting power shall include both permanently installed lighting systems as well as portable lighting systems, including individual task lights and furniture-mounted lighting.

Where certain automatic light controls are installed, lighting power in the proposed building may be adjusted by the power adjustment factors in Table G3.2. (Note that only one credit is allowed per space). Note that the adjustment factors vary depending on building size and hours of operation. Some automatic controls are already required for buildings with 5000 ft² of conditioned floor area and larger. (Note that this threshold is for the entire building area, not the size of a tenant space. Thus a 200 ft² tenant in a building with 7,500 ft² of conditioned floor would not qualify for the credit). Having an automatic lighting control such as an occupancy sensor or an automatic time switch reduces the time that the lighting system operates, but it is also acceptable to estimate this effect by reducing the connected lighting power.

For buildings (not tenant spaces) less than 5,000 ft² in conditioned floor area, a programmable timing control is estimated to reduce hours of operation by 10% and may be estimated by reducing connected lighting power by 10%. Remember that energy equals power times time, so a 10% reduction in either is equivalent. For buildings larger than this, the lighting requirements already require an automatic control, so this feature must be modeled in both the proposed building and the baseline building and no credit is allowed.

Occupant sensors alone or a combination of occupancy sensors and programmable timing controls have a 15% power adjustment factor for daytime occupancies and buildings less than or

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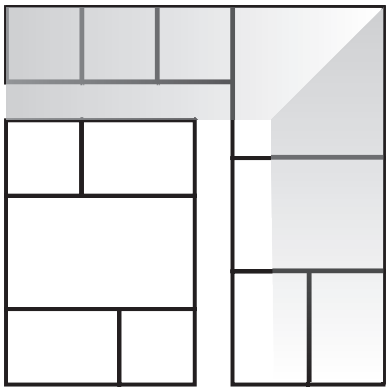

Figure G-D—Thermal Zoning in Building Simulation When the HVAC Zones Are Not Yet Designed

equal to 5,000 ft². The power adjustment factor is 10% for all other buildings.

Another way to take credit for automatic lighting controls that are not part of the baseline is to make an adjustment in the lighting schedule. This approach may be appropriate for daylighting controls, occupancy sensors and other types of controls. However, the burden is on the energy analyst to show that the schedule adjustment is warranted. Documentation may include supplementary daylighting calculations, monitored data from similar buildings or other evidence.

Baseline Building Lighting System

The interior lighting power density (LPD) for the baseline building shall be determined using one of the two methods. Either the building area or space-by-space method may be used, but the categorization of spaces must be identical between the proposed building and the baseline building.

The LPD for the proposed design is taken from the design documents for the building. The LPD specified in the models must correspond to the spaces within each thermal block.

Any interior lighting system efficiency improvements or reductions in the proposed building are reflected as credits or debits in the building performance rating method.

Under the Standard, required lighting controls (primarily automatic shutoff controls) are modeled using the lighting schedules. No additional automatic lighting controls (e.g., programmable controls or automatic controls for daylight utilization) shall be modeled in the baseline building design, as the lighting schedules used are understood to reflect the mandatory control requirements in the Standard.

Daylighting controls are not modeled in the baseline building model but may be modeled in the proposed building model. Ideally, these controls would be modeled with an hourly energy analysis program that contains an algorithm that assesses and responds to the daylighting received in the space for each hour.

If the proposed building has automatically controlled shading devices, then these may be modeled to reflect realistic assumptions about occupants closing blinds and drapes when direct sunlight creates too much glare. No interior blinds or drapes are modeled if the proposed building does not have automatic control.

Modeling of the controls should also reflect whether all the lamps in a fixture are dimmed together or step-switched on and off one by one. If there are any areas of the building for which the lighting systems are not defined, then those areas are modeled using base LPDs for both the proposed and budget runs (based on the building area method), and their lighting systems are energy neutral for the building performance rating.

The proposed building may include power adjustment credits for occupant sensors or automatic time switches (when they are not already required by the mandatory provisions). Adjustments to the lighting schedule may also be included in the proposed building to capture savings from daylighting or other lighting controls, but these adjustments are subject to the approval of the rating authority.

Exterior lighting is included in the building performance rating calculations. For exterior grounds lighting, the lighting efficacy must be a minimum of 60 lumens per watt for both the proposed building and the baseline building.

Other than cases where the lighting is exempted, credit may be taken for improvements in exterior lighting efficacy or wattage. If the proposed building does not have an exterior lighting application (for instance a parking lot that is not lighted), the baseline building shall not have the exterior lighting application either. If the lighting application exists, however, then the proposed building can take credit for a more efficient system.

Mandatory Provisions

For lighting, the mandatory provisions are described in § 9.4. Some mandatory provisions worth highlighting are:

- Building exterior lighting (§ 9.4.1.3, (§ 9.4.4, § 9.4.5, exception to (§ 9.4.5);
- Automatic shutoff for lighting in buildings larger than 5000 ft² (§ 9.4.1.1, exceptions to § 9.4.1.1);
- Automatic shutoff for exterior lighting (§ 9.4.1.3, exception to 9.4.1.3);
- Separate controls for display lighting (§ 9.4.1.4a);
- Master/control device for lighting in hotel/motel guest rooms (§ 9.4.1.4c);
- Tandem wiring for three-lamp ballasts (§ 9.4.2);
- Maximum wattage for exit signs (§ 9.4.3).

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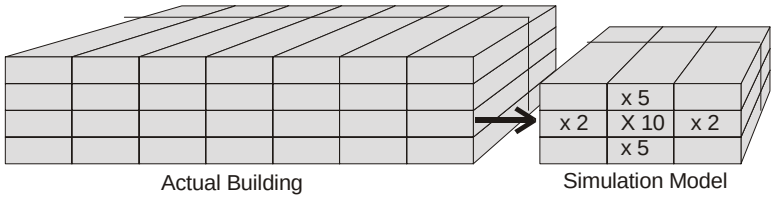

Figure G-E—Thermal Blocks for Apartment Building

Again, these mandatory requirements cannot be traded off.

Thermal Blocks—General Discussion

The building performance rating method distinguishes between HVAC zones and thermal blocks. An HVAC zone is physically determined by the design of the HVAC system. It includes some number of thermodynamically similar spaces whose loads can be satisfied through use of a single thermostat (or other type of temperature control). A thermal block is a simulation program term. It is similar to an HVAC zone, except that often in simulation practice a number of zones, which have similar loads and are served by similar systems, are combined into a single thermal block for modeling purposes.

Grouping HVAC zones into thermal blocks requires engineering judgment to avoid modeling errors, but when it is done reasonably, there is no significant loss of accuracy. For example, the interior HVAC zones of a multi-story building may be physically separate zones on each floor, but they may often reasonably be combined into a single thermal block in the simulation model of the building because they have similar loads and are served by similar systems. However, a cafeteria or computer room in an office building would need to be modeled separately, as would lower-floor retail uses. The basic rule of the proposed building rating method is that thermal blocks must be defined identically for the proposed building and the baseline building. This is consistent with the rule that the shape and area of the building envelope for the baseline building design be the same as for the proposed building, that the space use classifications be the same, and so forth.

Thermal Blocks—HVAC Zones Designed (Table G3.1-7)

HVAC zones may be combined into thermal blocks for modeling purposes (or multipliers may be used) when *all* the following conditions are met:

1. All of the space use classifications are the same . This ensures that they have the same load and schedule characteristics.
2. For exterior HVAC zones with glazing, the glazing for all zones included in the thermal block must have the same orientation, or at least their orientations must be within 45 degrees of each other. This ensures that they have approximately the same solar heat gain characteristics. This is not to say that the zones may not have two or more glazing orientations—a corner office could easily have two—but that the zones must have similar orientations. It would be acceptable, for example, to group all of the northeast corner offices on the intermediate floors of an office tower into a single thermal block.
3. All of the HVAC zones in the thermal block must be served either by the same HVAC system or by the same kind of HVAC system. This is so that the simulation program can accurately model the performance of the system(s) serving the block.

Thermal Blocks—HVAC Systems Not Designed (Table G3.1-8)

When HVAC zones are not designed at the time of the building performance rating, then the configuration of the thermal blocks must be assumed (Table G3.1-8b). This situation is quite common in commercial buildings where the future tenants will determine the zoning of spaces in the building. In this case, thermal blocks must be defined based on similar internal load densities, occupancy, lighting, thermal and space temperature schedules, etc.

The following rules shall be followed in creating the zoning for these cases.

1. *Separate interior and perimeter spaces.* Assign separate thermal blocks to interior spaces located more than 15 feet from an exterior wall and to perimeter spaces within 15 feet of the exterior (see Example G-B and Figure G-D).
2. *Separate glazing orientations.* Glazed exterior walls should be assigned to different perimeter thermal blocks for each major orientation. Orientations within 45 degrees of each other may be combined. Spaces with two or more glazed orientations, such as corner offices, should be divided proportionately between zones having the different orientations. Figure G-D shows a strategy for allocating corners to two different thermal blocks.
3. *Separate top, bottom, and middle floors.* Spaces exposed to ambient conditions, such as the top floor or an overhanging floor, and spaces in contact with the ground, such as the ground floor, must be zoned separately from zones that are not exposed to ambient conditions, such as intermediate floors in a multi-story building.

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Thermal Blocks in Multifamily Residential Buildings (Table G3.1-9)

Multifamily residential buildings are another special case for the creation of thermal blocks. In general, each residential space must be treated as separate thermal blocks, except that some combinations are allowed. Units all facing the same orientation, and having similar conditions at the top, bottom, and sides, may be combined. Similar corner units may be combined, and units with similar roof or floor loads may be combined (see Figure G-E).

HVAC Systems (Table G3.1-10)

Buildings With Incomplete Energy System Design

Some buildings, such as retail malls and speculative office buildings, typically are built in phases. For example, the core mechanical system may be installed with the base building, while the ductwork and terminal units are installed later as part of tenant improvements. A similar situation can occur with the lighting system or with the building's other energy-related features.

For the purpose of calculating the proposed building performance rating, the rule is simple: future energy features that are not yet designed or recorded in the construction documents are assumed to minimally comply with the applicable mandatory provisions and prescriptive requirements. In cases where the space use classification is not known, the default assumption is to classify it as office space using the building area method.

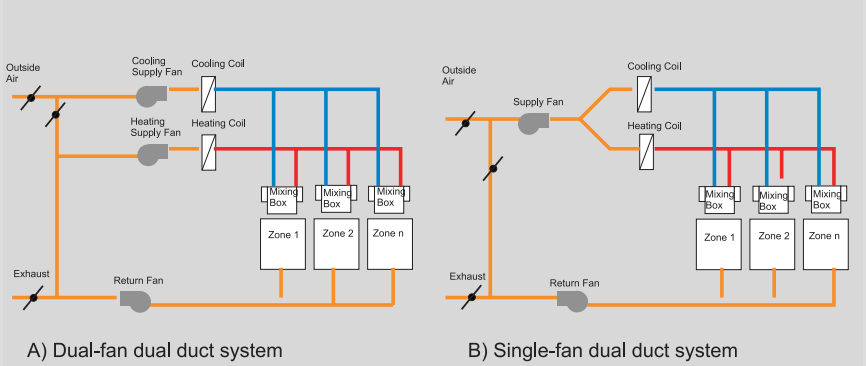
Requirements for both Heating and Cooling

The building performance rating method, and indeed the rest of the Standard, is

Example G-E—Dual-Fan Duct System Modeling

Q

A proposed design has a dual-fan dual-duct system as in Design A. Some building simulation programs are able to model only single-fan dual-duct systems as represented in Design B. The dual-fan system is more energy efficient than the single-fan system because the heating coil is not heating relatively cool outdoor air when the outdoor air damper is open (economizer cycle). How would the proposed design be modeled using the performance rating method?



A) Dual-fan dual duct system

B) Single-fan dual duct system

A

A thermodynamically similar model to the dual-fan dual-duct system can be created by running the single-fan dual-duct model twice—once under normal conditions and recording all outputs except heating outputs and then a second time with no outdoor air and recording only the heating outputs. The combined recorded outputs capture the simultaneous cooling and re-heating aspects as well as the benefits of higher air temperatures entering the heating coil.

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based on the assumption that buildings are heated and cooled. Even if not installed initially, it is common for buildings lacking a heating or cooling system to have one retrofitted by future occupants.

Accordingly, there is a special rule for calculating the proposed building performance rating when a building's HVAC system is heating-only or cooling-only: the building must be modeled as if it had both heating and cooling. The missing system is modeled the same as the baseline building (defined later in this chapter). The same system is modeled for both the proposed building and baseline building simulations.

This requirement only applies to conditioned spaces in the building. Semiheated spaces would only have a heating system; unconditioned spaces would have neither heating nor cooling systems.

The proposed building default cooling system does not exclude natural ventilation from consideration. It just means that the proposed building is modeled as a "hybrid system" where cooling is provided by natural ventilation when conditions are acceptable and by the default mechanical cooling system when natural ventilation is inadequate to provide thermal comfort.

HVAC Systems

The HVAC system in the proposed building design shall be that shown on the construction documents if the system has been designed. The basic rule for modeling HVAC systems for the proposed building is to base the model as completely as possible on the actual system design as shown in the construction documents. This includes the system type, equipment capacities and efficiencies, controls, ancillary features (such as economizers), etc. The equipment efficiencies may need to be adjusted to meet the needs of the simulation program. While efficiencies may be most accurately specified at the building's design conditions, most simulation programs require efficiencies to be specified at standard rating conditions, such as those given in § 6.4.1 of the Standard. If that is the case, than the efficiency values needed by the simulation program should be used in the modeling.

Some special cases related to HVAC systems need to be considered:

1. *A complete HVAC system exists.* An example might be an existing speculative building that is being built out for a tenant. The variations in the performance rating would be limited to the interior construction and lighting system. In a case like this, the proposed building and baseline building models are the same and are based on the existing HVAC system.
2. *No heating system exists.* If no heating system exists, a default heating system must be assumed and modeled for the proposed building. The system should be electric and equal to the baseline building definition, which is defined later in this Chapter.
3. *No cooling system exists.* If no cooling system exists, a default cooling system must be assumed and modeled. It shall be identical to the system in the baseline building, as defined later in this Chapter.

Baseline HVAC Systems

The baseline building HVAC system is defined based on the size of the proposed building, the number of floors and the building type or use (residential or nonresidential). In contrast to the ECB Method where the budget building HVAC system is largely defined by the proposed building HVAC system, the baseline building HVAC system is mostly independent of the proposed building system, except for just a few features such as the heating source. If the proposed building has electric heat so does the baseline building, and if the proposed building has gas, oil or propane (any fossil fuel), the baseline building has the same heating source.

Most of the details of the baseline building HVAC system are also independent of the proposed building, such as fan power, the type and number of boilers and chillers, the type of cooling tower, chilled water and hot water supply temperatures, supply air temperature, and temperature reset schedules.

By defining the baseline building HVAC system independently of the proposed building system, more credit is offered for energy efficiency measures such as system choice and design. With the ECB Method, the budget building system tends to follow the proposed design, e.g. if the designer reduces fan pressure through appropriate duct design, the budget building assumes the same fan pressure and no credit is offered.

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Baseline HVAC System Type and Description

The performance rating rules for the baseline building HVAC system are shown in Table G-A. This table shows the baseline building system types, based on building type (nonresidential or residential), the number of floors, the floor area and the heating source (electric or other). Note that a hybrid system refers to a system with any combination of fossil and electric heat, and the baseline system for this is a fossil fuel system.

For systems 1, 2, 3, and 4, each thermal block shall be modeled with its own HVAC system. For systems 5, 6, 7, and 8, each floor shall be modeled with a separate HVAC system. Floors with identical thermal blocks can be grouped for modeling purposes.

For laboratory spaces with a minimum exhaust of 5000 cfm, the HVAC system type should be 5 or 7 and reduce the exhaust and makeup air volume to 50% of design values during unoccupied periods. For all electric buildings the heating shall be electric resistance.

Residential spaces in buildings are used primarily for living and sleeping. They include, but are not limited to, dwelling units, hotel/motel guest rooms, dormitories, nursing homes, patient rooms in hospitals, lodging houses, fraternity/sorority houses, hostels, prisons, and fire stations. The scope of Standard 90.1, in terms of residential spaces, applies just to spaces with four or more stories, so low-rise residential is excluded.

For residential buildings, the system type is independent of building floor area or number of stories (although all residential buildings covered by the Standard will have more than three floors). The only factor is the heating source. For buildings with all electric heat, the baseline building system is a packaged thermal electric heat pump serving each dwelling unit or guest room. For buildings with any fossil fuel heating, the baseline building system is a packaged terminal air conditioner with a hot water coil and a central boiler. Both systems have a direct expansion cooling system and a fan that delivers a constant volume of air.

For nonresidential buildings, the baseline building system type depends not only on the heating source for the proposed building, but also on the number of floors and the total conditioned floor

Table G-A—Baseline Building HVAC System Types and Descriptions

This table combines Table G3.1.1A and Table G3.1.1B from Standard 90.1-2007 *for ease of use and clarity. The building types and sizes are shown as columns. System types and specifications are shown in rows. These are grouped first by proposed buildings that use fossil fuels and then by proposed buildings that use electricity.*

			Nonresidential		
Heating Source		Residential More than 3 stories	Less than 4 floors and less than 25,000 ft²	4 or 5 floors and less than 25,000 ft² or 5 floors or less and 25,000–150,000 ft²	More than 5 floors or more than 150,000 ft²
Fossil Fuel, Fossil/Electric Hybrid & Purchased Heat	Number/Code	1—PTAC	3—PSZ-AC	5—PVAV w/Reheat	7—VAV w/Reheat
	System Type	Packaged terminal air conditioner	Packaged rooftop air conditioner	Packaged rooftop variable air volume with reheat	Variable air volume with reheat
	Fan Control	Constant Volume	Constant Volume	VAV	VAV
	Cooling Type	Direct Expansion	Direct Expansion	Direct Expansion	Chilled Water
	Heating Type	Hot Water Fossil Fuel Boiler	Fossil Fuel Furnace	Hot Water Fossil Fuel Boiler	Hot Water Fossil Fuel Boiler
Electric and Other	Number/Code	2—PTHP	4—PSZ-HP	6—PVAV w/ PFP Boxes	8—VAV w/ PFP Boxes
	System Type	Packaged terminal heat pump	Packaged rooftop heat pump	Packaged rooftop variable air volume with reheat	Variable air volume with reheat
	Fan Control	Constant Volume	Constant Volume	VAV	VAV
	Cooling Type	Direct Expansion	Direct Expansion	Direct Expansion	Chilled Water
	Heating Type	Electric Heat Pump	Electric Heat Pump	Electric Resistance	Electric Resistance

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area of the building.

For smaller nonresidential buildings that are less than 25,000 ft² and less than three stories, the baseline building HVAC system is a rooftop packaged system serving each thermal zone (or thermal block). When the proposed building has only electric heat, the heating source for the baseline building system is a heat pump (the air conditioner has a reversing valve). When the proposed building includes any other type of heating, the baseline building system has a furnace that uses the same fuel as the proposed building. In both cases, the systems are constant volume with a direct expansion coil in the air stream.

For larger nonresidential buildings, that are more than 150,000 ft² or more than 5 stories, the baseline building HVAC system is a variable air volume system with a central chilled water plant. If the heating source in the proposed building is all electric, then each zone has a parallel type fan powered (PFP) mixing box with electric resistance reheat. If another heating source (non-electric) is used anywhere in the **non-residential systems** of building, the system is a "hybrid" and, then reheat at the zones is provided by hot water coils served by a central hot water boiler. Also with non-electric heating sources, conventional VAV boxes are used for zone control rather than PFP boxes.

For intermediate-sized buildings that are 4 or 5 floors and less than 25,000 ft² or less than 6 floors and between 25,000 and 150,000 ft², the baseline building HVAC system for electric heat is a packaged variable air volume (PVAV) system. When the proposed building has electric heat, then the baseline building system has parallel type fan powered (PFP) mixing boxes electric resistance heating both at the air handler and at the PFP VAV boxes. When the proposed building has any non-electric heating source, then conventional VAV boxes serve the thermal zones and heating is provided by a hot water boiler that uses the same fuel as the proposed building. VAV systems are to be modeled as floor-by-floor so that they can serve areas with differing occupancy and operating schedules.

If a building has both residential and nonresidential spaces with their total conditioned floor area both greater than 20,000 ft², for instance a residential tower with retail and restaurants at the base, then the HVAC system type is determined separately for the residential and nonresidential portions.

Purchased Heat (§ G3.1.1.1)

For proposed building systems using purchased hot water or steam, the baseline building shall use the same hot water or steam source as used for the proposed building and without on-site boilers. Costs shall be based on actual utility rates for the purchased steam or hot water.

General Baseline HVAC System Requirements (§ G3.1.2)

This section describes the general requirements for the baseline building HVAC system. The requirements in this section are

Example G-F—Natural Ventilation

Q

An energy analyst performed computational fluid dynamics (CFD) for a typical classroom in a new school and determined that when the outdoor temperature is below 63 ºF and wind speed is greater than 3 mph, the cooling load in the space may be satisfied by opening the windows. Based on the CFD analysis, and an evaluation of the climate data for the site, the analyst developed schedules that increase infiltration (to approximate natural ventilation), shut down the fans, and turn off the cooling during periods when opening the windows has been determined to meet the cooling load. Is this an acceptable modeling approach?

A

Yes. As long as the space does not have a cooling system the rating authority approves the proposed procedure. The default HVAC system, as defined in Table G3.1-1, provides cooling during periods of time when natural ventilation is not adequate.

If the space has a permanent cooling system, then the fans are required to run constantly during occupied periods and no credit is available for natural ventilation.

The energy analyst will also need to show that the *Standard 62* outdoor air ventilation requirement is met by operable windows. This means that all areas within the naturally ventilated space shall be within 20 ft of an operable window and that the operable window area is at least 5% of the naturally ventilated floor area.

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Equipment Efficiencies (§ G3.1.2.1)
The minimum efficiencies for HVAC equipment (§ 6.4.1) must be used for the applicable equipment in the baseline building design. This includes any part-load efficiencies if these are specified. For instance, smaller equipment, which is regulated by NAECA, is rated both in terms of an SEER and an EER. These efficiency requirements define the baseline building equipment performance.

Many types of HVAC equipment have overall efficiency ratings that include the supply fan power. A good example is the energy efficiency ratio (*EER*), which compares the net cooling effect in Btu/h to the total input power of the packaged system in watts to drive the supply and condenser fans and the refrigerant compressor.

When the HVAC system performance is defined in terms of an overall figure like *EER*, it is necessary for the simulation models of both the proposed and baseline building designs to separate supply fan energy from cooling system energy. The compressor and the fans would also be controlled differently, so their operating profiles must reflect their actual operation. This improves the accuracy of the simulation, since the energy needed to deliver conditioned air into spaces in the building relies on different physical principles than the energy needed for cooling. Also, since fans are required to run constantly when the building is occupied, separating fan and cooling energy addresses this explicitly.

Manufacturers of HVAC equipment publish a variety of sizing parameters that can assist in calculating the coefficient of performance (*COP*), the ratio of cooling energy provided per unit of energy input into the cooling section (compressor and condenser) of packaged HVAC equipment. The performance of this cooling section is a function of supply

Example G-G—Calculating *COP* for Compressor and Condenser

Q

A 15-ton packaged rooftop single-zone system having an *EER* of 9.7 (*COP* of 2.75) is specified for a building. The following table gives the design specifications. How should this be modeled?

EQUIPMENT PARAMETER	VALUE
Net Cooling Capacity (Btu/h)	174,000
Total Packaged Unit Input Power (W)	17,938
EER	9.7
Gross Cooling Cap (ARI conditions)	*182,000*

A

The supply fan power is the difference between the gross and the net cooling capacity.

$$\text{Supply Fan Power} = \frac{(182{,}000 - 174{,}000)[\text{Btu/h}]}{3.413[\text{Btu/W} \cdot \text{h}]} = 2343 \text{ W}$$

From the equation for cooling system *COP*, the cooling provided by the compressor and the condenser into the airstream in Btu/h per Btu/h of electrical power input is:

$$\text{COP} = \frac{182{,}000\,[\text{Btu/h}]}{(17{,}938 - 2343 \text{ W}) \times (3.413 \text{ Btu/W} \cdot \text{h})} = 3.42$$

Some simulation programs use an energy input ratio (*EIR*), which is 1/*COP*. In this case, the *EIR* for this piece of equipment would be 1/3.42 or 0.292.

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airflow rate, outdoor dry-bulb temperature, and the wet-bulb and dry-bulb temperature of air entering the cooling coil. In general, simulation programs require the rated performance of the equipment at ARI (Air-Conditioning and Refrigeration Institute) standard test conditions: 95°F outdoor dry-bulb temperature and 80°F dry-bulb, 67°F wet-bulb temperature of air entering the evaporator coil.

The simulation program will use an overall coefficient of performance (*COP*) for the cooling section of packaged HVAC equipment (see Equation (G-B). If the supply fan watts at ARI conditions are available, the *COP* can also be expressed as Equation (G-C.

Equation (G-C illustrates the process of calculating a *COP* for the compressor and the condenser. Note, however, that this *COP* by itself does not yield the energy consumption of the cooling section of packaged HVAC systems; it is used in conjunction with other variables, such as the load placed upon the system, ambient air temperature, and the psychrometric properties of the air entering the cooling coil.

Note that the minimum equipment efficiencies are a mandatory provision. As such, these minimum efficiencies must always be complied with and cannot be traded off (though credit can be taken for higher equipment efficiencies).

Equipment Capacities (§ G3.1.2.2)

The sizing of equipment can have a significant impact on system efficiency, depending on how efficient the equipment is at part load and how often it operates at part load. The building performance rating rules are designed to properly size the equipment in the baseline building and to prevent equipment in the proposed building from being undersized and not providing adequate comfort.

Properly sizing equipment in the baseline building reduces the possibility of gamesmanship. For example, if the proposed design was sized to have good part-load performance and the budget building design was sized to have poor part-load performance, then this would show up in the building performance rating. This is not a real savings, however, because the sizing of the budget building design is arbitrary.

The rule for sizing equipment is different for the ECB Method and the building performance rating method. With the ECB Method, the sizing ratio of the proposed building is maintained in the budget building. For instance, if a chiller in the proposed building is 50% oversized, then the chiller in the budget building is also 50% oversized. However with the building performance rating method, equipment in the baseline building is oversized by a fixed amount in all cases.

The equipment size for the baseline building is determined separately for each orientation, and the peak capacity of cooling equipment is then made 15% larger than the value calculated from the simulation program. The peak capacity of the heating equipment is made 25% larger. In other words, the calculated peak load from the simulation results for cooling are multiplied times 1.15 and the heating results are multiplied times 1.25. As mentioned before, this process is repeated for each rotation of the baseline building, as required by Table G3.1-5.

To verify that the baseline building and the proposed building have reasonable equipment sizes, a check is made with regard to hours during the simulation period when loads are not met. These "unmet load hours" are reported by DOE-2 and most other energy simulation programs. If "unmet load hours" are too high, this is an indication that the equipment is undersized.

In order for equipment to be acceptably sized under the rules of the building performance rating method, two conditions must be satisfied:

- First, the unmet load hours for both the proposed design and the baseline building designs shall not exceed 300 hours per year (of the 8,760 hours simulated).
- Second, the unmet load hours for the proposed design shall not exceed the number of unmet load hours for the baseline building design by more than 50.

If unmet load hours in the proposed building exceed the unmet load hours in the baseline building by more than 50, then the size of equipment in the baseline building shall be reduced incrementally, until the condition is satisfied.

If unmet load hours for either the proposed design or baseline building design exceed 300, then the simulated capacities shall be increased incrementally, and the building with unmet loads shall be re-simulated until the unmet load hours are reduced to 300 or less. For the proposed building, this means that the construction drawings may need to be modified and larger equipment specified.

In some cases, unmet load hours exceeding these limits may be accepted at the discretion of the rating authority provided that sufficient justification is given indicating that the accuracy of the simulation is not significantly compromised by these unmet loads. However, in all cases it is important that the unmet load hours of the proposed design not exceed that of the baseline design by more than the stated 50 hours. This is to ensure that energy savings are not claimed in the proposed design via providing a lower level of performance than in the baseline building.

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The weather conditions that are used to size equipment may be based either on the hourly weather file used in the simulation or based design days developed using 99.6% heating design temperatures and 1% dry-bulb and 1% wet-bulb cooling design temperatures. If the simulation weather file is used, then it should contain peak conditions that are representative of the area.

Preheat Coils (§ G3.1.2.3)
"If the HVAC system in the proposed design has a preheat coil and a preheat coil can be modeled in the baseline system, the baseline system shall be modeled with a preheat coil controlled in the same manner as the proposed design." This means that adding a preheat coil is not something that can be credited towards a building performance rating.

Fan System Operation (§ G3.1.2.4)
The section states, "Supply and return fans shall operate continuously whenever spaces are occupied and shall be cycled to meet heating and cooling loads during unoccupied hours. If the supply fan is modeled as cycling and fan energy is included in the energy-efficiency rating of the equipment, fan energy shall not be modeled explicitly."

The first rule says that fans shall be assumed to operate continuously when the space is occupied. Therefore, the only time that fans are allowed to cycle is during unoccupied hours.

Many simple thermostats are designed with an "automatic" and "on" switch. When the switch is set to "automatic", the fans cycle with loads. Frequently, outdoor air ventilation is not adequately provided when the thermostat is set to this mode.

Supply, return and/or exhaust fans shall remain on during occupied and unoccupied hours in spaces that have health and safety mandated minimum ventilation requirements during unoccupied hours. This is meant to prevent a proposed system with unoccupied ventilation requirements (such as a bio-safety lab) from being penalized by comparing it to a baseline system that does not ventilate during unoccupied hours.

Ventilation (§ G3.1.2.5)
Outdoor air ventilation can be a major contributor to building energy consumption, but it is not considered an opportunity for energy savings under the building performance rating method. The minimum ventilation rates designed for the proposed building (not counting extra ventilation for economizer cooling) must also be modeled the same in both the baseline building and the proposed building. In other words, ventilation rates are the same in both models, and ventilation is energy neutral as far as trade-offs are concerned.

The only exception to this rule is when the proposed building uses carbon dioxide sensors to modulate outdoor air in response to occupant loads. If demand control ventilation is not required as a prescriptive requirement, then a different (reduced) outdoor air rate may be modeled

(G-A)

$$EER = \frac{\text{Net Cooling}[\text{Btu}/\text{h}]}{\text{Total Input Power}[\text{W}]} = \frac{(\text{Gross Cooling} - \text{Supply Fan Power})[\text{Btu}/\text{h}]}{\text{Total Input Power}[\text{W}]}$$

(G-B)

$$\text{COP} = \frac{\text{Gross Cooling Capacity } [\text{Btu/h}]}{(\text{Compressor W} + \text{Condenser Fan W}) \times (3.413 \text{ Btu/W} - \text{h})}$$

(G-C)

$$\text{COP} = \frac{\text{Gross Cooling Capacity } [\text{Btu/h}]}{(\text{Total Unit W} - \text{Supply Fan W}) \times (3.413 \text{ Btu/W} - \text{h})}$$

Note: The difference between the net cooling capacity and the gross cooling capacity is the heat introduced into the air stream by the fan.

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for the proposed building.

Economizers (§ G3.1.2.6)
Whether or not the baseline building HVAC system has an economizer depends on the type of system for the baseline building (see Table G-A). HVAC systems 1 and 2 will never have an economizer; systems 3 through 8 will have an economizer if the building is not located at climate zone 1A, 1B, 2A, 3A, or 4A.

The baseline building HVAC system shall not have an economizer for one or both of the following conditions:

(a) Systems that include gas phase air cleaning to meet the requirements of 6.1.2 of ANSI/ASHRAE *Standard 62.1-2004*; This exception should only be used if the system in the proposed building does not use an economizer.

(b) Where the use of outdoor air for cooling will affect supermarket open refrigerated casework, and the system in the proposed building does not use an economizer.

Economizer High-Limit Shutoff (§ G3.1.2.7)
When an economizer is required, it must have a high-limit shutoff switch that senses dry-bulb temperature and shuts off economizer operation (reduces outdoor air to the minimum required for ventilation) when the outdoor temperature exceeds the values shown in Table G3.1.2.6C. The specific high-limit shutoff temperature depends on the climate zone.

Humidification and Economizers

The drybulb high-limit economizers may increase energy use in dry or cold climates when spaces are humidified. This does not preclude modeling the baseline system with that humidification and economizer.

Example G-H—Economizer Requirements, North Carolina

Q

Does the baseline building HVAC system for a two-story 40,000 ft² office building in Ashville, North Carolina require an economizer? The proposed building is served by a central VAV system with a hot water gas fired boiler.

A

Using Table G3.1.1A, the baseline building HVAC system type is a packaged single zone air conditioner (HVAC System 3 – PSZ-AC). A separate system serves each of the thermal blocks modeled in the proposed building.

According to Table B-1, Ashville belongs to climate zone 4A. Referring to Table G3.1.2.6A, there is no requirement of an economizer.

Example G-I—Economizer Requirements, San Francisco

Q

If the building in the previous example were in San Francisco, California, would it be required to have an economizer?

A

Based on Table B-1, San Francisco belongs to climate zone 3C. Referring to Table G3.1.2.6A, an economizer is required for the baseline system.

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Design Air Flow Rates (§ G3.1.2.8)
The quantity of air supplied to spaces in a building can have a significant effect on energy use in the baseline building. The supply air quantity modeled for the baseline design must be based on a supply-air-to-room-air temperature difference of 20°F, or the required ventilation air or make up air whichever is greater. If the space is maintained at 75 °F, then supply air would be assumed to be delivered at 55 °F.

The volume of air modeled for the proposed building may be greater or less, depending on design conditions. This gives designers the ability to select supply air temperatures or to reset design air temperatures to optimize energy performance and to gain credit for these measures through the building performance rating method.

If return or relief fans are specified in the proposed design, then the baseline building design shall also be modeled with return or relief fans. Return or relief fans in the baseline building shall be sized for the supply air volume less the minimum outdoor air that is required for the spaces served by the system. However, the return fan shall be sized for at least 90% of the supply air volume.

Supply Fan Power (§ G3.1.2.9)
With the ECB Method, the static pressure and other factors are set equal to the proposed design so that there is little or no credit for efficient fan systems. However, with the building performance rating method, the supply fan power is specified independently of the proposed building, enabling credit for more efficient fan systems. System fan electrical power for supply, return, exhaust and relief fans is calculated based on the following formula. The power from this formula includes supply, return, relief, and exhaust

Example G-J—Baseline Building Peak Fan Power

Q

The supply air volume for an 80,000 ft² medical office building is 120,000 cfm, as determined by the simulation program using a 20 ºF temperature difference between space temperature and supply air temperature as required by § G3.1.2.8. The baseline building HVAC system is system 5 (packaged VAV with a gas furnace). What is the baseline building peak fan power?

A

Using the equation from Table G3.1.2.9, the brake horsepower for the baseline fan system is 136.5 hp as calculated below:
bhp = 0.0013 × CFM_S + A
bhp = 0.0013 × 120000 + 0
bhp = 156
Lookup Table 10.8 for the next size greater than 156 bhp using the enclosed motor at 1800 rpm, the fan motor efficiency is 95%, therefore, the fan power is 122,501 W, as calculated below:
Pfan = bhp × 746 / Fan Motor Efficiency
Pfan = 156 × 746 / 0.95
Pfan = 122,501 Watts

Example G-K—Fan Energy

Q

A special classroom for children with respiratory problems has a HEPA (high efficiency particulate air) filter that adds 1.25 in. w.c. to the pressure drop across the fan. The single-zone system (System 3 PSZ-AC) for the classroom delivers 1,500 cfm of supply air. Is it possible to adjust the fan energy in the baseline building to account for this?

A

Yes. The exception to G3.1.2.9 allows such an adjustment. The added fan power is 403 W, as calculated below:
bhp Credit A = 1.25 × 1500 / 4131 = 0.454
Total fan bhp = 0.00094 × CFM_S + A = 0.00094 × 1500 + 0.454 = 1.864
The fan motor efficiency is 84% from Table 10.8, therefore, the fan power
Pfan = 1.864 × 746 / 0.84 = 1655 Watts
Without the filter credit,
Fan bhp = 0.00094 × 1500 = 1.41
From Table 10.8, fan motor efficiency = 84%
Pfan = 1.41 × 746 / 0.84 = 1252 Watts

Therefore, the fan power credit is 1655 – 1252 = 403 Watts

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fans, but excludes power to fan-powered VAV boxes when these are part of the baseline building HVAC system (systems 6 and 8).

(G-D)

For Systems 1 and 2,

$$P_{fan} = 0.3 \times CFM_S$$

For Systems 3 to 8,

$$P_{fan} = bhp \times 746 / \eta_m$$

For constant volume systems 3 and 4,

$$bhp = 0.00094 \times CFM_S + A$$

For variable volume systems 5 to 8,

$$bhp = 0.0013 \times CFM_S + A$$

Where,

P_{fan} = electric power to fan motor (Watts).

bhp = brake horsepower of baseline fan motor

η_m = fan motor efficiency from Standard 90.1-2007 Table 10.8 for the next motor size greater than the bhp using the enclosed motor at 1800 rpm.

CFM_S = the baseline fan design supply air flow in cfm

A = pressure drop adjustment defined in Section 6.5.3.1.1.

Pressure Drop Adjustments

When the proposed HVAC system has special filtration requirements, ducted return, or other devices listed in Table 6.5.3.1.1B, the fan power for the baseline building system is adjusted upwards to account for this. The pressure drop adjustment is not applicable to evaporative coolers or heat recovery devices that are required in the baseline systems.

The allowable fan system power in the baseline design system serving the same space may be increased using the following pressure credit.

(G-E)

$$A = \sum \frac{PD \times CFM_D}{4131}$$

Where:

PD = each applicable pressure drop adjustment from Table 6.5.3.1.1B in in. w.c.

CFM_D = the design airflow through each applicable device from Table 6.5.3.1.1B in cfm

Exhaust Air Energy Recovery (§ G3.1.2.10)

Exhaust air energy recovery is required for fan systems that are larger than 5,000 cfm and which also require a significant amount of outdoor air (70% or more of the supply air volume). The energy recovery system in the baseline building shall have a recovery effectiveness of at least 50%. In this context, recovery effectiveness is the difference between the enthalpy of the outdoor air and return air at design conditions.

The energy recovery system does not negate the requirement for an outdoor air economizer, when this is required for the baseline building system. Furthermore, the baseline building system must permit air to bypass the energy recovery system during economizer operation.

There are exceptions to the heat-recovery requirements for mild climates, semiheated spaces with no air-conditioning, systems that exhaust toxic fumes or kitchen grease, systems serving laboratories with exhaust rate of 5,000 cfm or greater, and other conditions (See Exceptions to G3.1.2.10).

System-Specific Baseline HVAC System Requirements (§ G3.1.3)

Heat Pumps (§ G3.1.3.1)

The electric heat pumps used for baseline building systems 2 and 4 shall be modeled with electric auxiliary heat. The heat pump systems shall be controlled with multi-stage space thermostats and an outdoor air thermostat wired to energize auxiliary heat only on the last thermostat stage and when outdoor air temperature is less than 40 °F.

Type and Number of Boilers (§ G3.1.3.2)

Baseline building systems 1, 5, and 7 shall have one or more fossil fuel boiler as the heating source and the boiler plant shall use the same fuel as the proposed building. However, if the proposed building uses purchased hot water or steam, the baseline building shall also use purchased hot water or steam at the same utility rate as the proposed building.

Hot water plants that serve a conditioned floor area of 15,000 ft² or less shall have a single boiler. Plants serving more than 15,000 ft² shall have two equally sized boilers, which shall be controlled to come on sequentially as needed to meet the load.

Hot Water Supply Temperature (§ G3.1.3.3)

For baseline building systems 1, 5, and 7 (except when the proposed building uses purchased steam or hot water), the hot water supply temperature shall be modeled at 180 °F with a 130 °F return temperature, subject to the reset schedule shown below. Piping losses shall not be modeled in either the baseline building or the proposed building model.

Hot Water Supply Temperature Reset (§ G3.1.3.4)

For baseline building systems 1, 5, and 7, the hot water supply temperature shall be reset based on the outdoor dry-bulb temperature. When the outdoor temperature is 20 °F and below, the supply temperature shall be a constant 180 °F. When the outdoor temperature is 50 °F and above, the supply temperature shall be 150 °F. When the outdoor temperature is between 20 °F and 50 °F, the supply temperature shall be ramped in a proportional manner between 180 °F and 150 °F.

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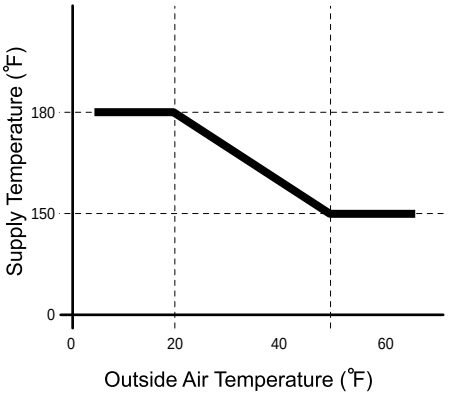

Figure G-F—Hot Water Temperature Reset Schedule

Mandatory Provisions
For HVAC, the mandatory provisions are in § 6.4. Some mandatory provisions worth highlighting are:

- Minimum HVAC equipment efficiencies (§ 6.4.1.1, § 6.4.1.2, § 6.4.1.3, and § 6.4.1.4);
- Controls for automatic shutdown, setback, and optimum start (§ 6.4.3.3.1, § 6.4.3.3.2, and § 6.4.3.3.3);
- Motorized dampers (§ 6.4.3.4.1, § 6.4.3.4.2, exceptions to 6.4.3.4.1 and § 6.4.3.4.2, § 6.4.3.4.3, exceptions to 6.4..3.4.3);
- Damper leakage rating (§6.4.3.4.4);
- Ventilation fan control (§6.4.3.4.5, exception to §6.4.3.4.5);
- Heat pump auxiliary heat control (§6.4.3.5);
- Requirements for freeze protection and snow/ice melting systems (§ 6.4.3.8);
- Ventilation controls for high occupancy areas (§ 6.4.3.9);
- Duct insulation (§ 6.4.4.1.2, exceptions to 6.4.4.1.2);
- Pipe insulation (§ 6.4.4.1.3, exceptions to 6.4.4.1.3);
- Duct sealing (§ 6.4.4.2.1);
- Duct leakage testing (§ 6.4.4.2.2);
- Completion requirements (§ 6.6.2).

Again, remember that these mandatory provisions cannot be traded off.

Hot Water Pumps (§ G3.1.3.5)
For systems 1, 5, and 7 (except for purchased hot water or steam), the baseline building design hot water pump power shall be 19 W/gpm. This is about equal to a pump operating against a 60 foot head with a 60% combined impeller and motor efficiency.

"The pumping system shall be modeled as primary-only with continuous variable flow. Hot water systems serving 120,000 ft² or more shall be modeled with variable-speed drives, and systems serving less than 120,000 ft² shall be modeled as riding the pump curve."

Piping Losses (§ G3.1.3.6)
For baseline building systems 1, 5, 7, and 8, "piping losses shall not be modeled in either the proposed or baseline building designs for hot water, chilled water, or steam piping." This is mainly a modeling issue. While pipe losses may be significant for energy performance, most energy simulation programs do not have procedures for modeling these losses (or gains in the case of chilled water).

Type and Number of Chillers (§ G3.1.3.7)
For baseline building systems 7 and 8, which have chilled water plants, water-cooled electric chillers shall be used for the baseline building no matter what the cooling energy source in the proposed building. Even though the proposed building may have gas engine driven chillers or absorption chillers, or purchased chilled water, the baseline building shall be modeled with electric chillers.

The type of chillers that are placed in the baseline building depends on the peak cooling load of the baseline building, which is different from the proposed building. If the building has a peak cooling load of 300 tons or less, then a single water-cooled screw chiller is modeled. For a peak cooling load greater than 300 tons but less than 600 tons, then two equally sized water-cooled screw chillers are modeled in the baseline building. For a peak cooling load that is 600 tons or greater, the baseline building is modeled with two or more water-cooled centrifugal chillers. In this case at least two equally sized centrifugal chillers are always modeled, but additional equally sized chillers are added as necessary so that all chillers are 800 tons are smaller.

Chilled Water Design Supply Temperature (§ G3.1.3.8)
For baseline building systems 7 and 8, the chilled water design supply temperature at design conditions shall be 44ºF and the return water temperature shall be 56ºF.

Chilled Water Supply Temperature Reset (§ G3.1.3.9)
For baseline building systems 7 and 8, the chilled water temperature shall be reset on an hourly basis, based on the outdoor air temperature. When the outdoor air temperature is 80 ºF or greater, the supply temperature shall be 44ºF. When the outdoor air temperature is 60ºF and below, the supply water temperature shall be 54 ºF. When the outdoor air temperature is between 60ºF and 80ºF, the supply water temperature shall ramp between 44ºF and 54ºF in a proportional manner. If there is dehumidification requirement of cooling coils, the maximum reset of chilled water temperature should be calculated according to the dehumidification requirement and cooling coils performance.

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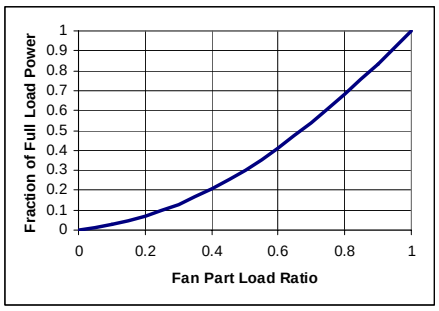

Figure G-G—Part-Load Performance of Baseline Building VAV Fan

Chilled Water Pumps (§ G3.1.3.10)
For baseline building systems 7 and 8, pump power shall be 22 W/gpm. This is about equal to a pump operating against a 75 foot head with a 60% combined impeller and motor efficiency.

Chilled water pumps in systems with a cooling capacity of 300 tons or more shall be modeled as primary/secondary systems with variable speed drives on the secondary pumping loop. Chilled water pumps in systems with less than 300 tons cooling capacity shall be modeled as primary/secondary systems with secondary pump riding the pump curve.

Heat Rejection (§ G3.1.3.11)
For baseline building systems 7 and 8, the heat rejection device shall be an axial fan cooling tower with two-speed fans. Baseline cooling tower power should be calculated using Table 6.8.1G.

Condenser water design supply temperature shall be 85ºF or a 10ºF approach to design wet-bulb temperature, whichever is lower. The design temperature rise shall be 10ºF. In dry climates, baseline condensing conditions may differ dramatically from design conditions or simulation defaults.

The tower shall be controlled to maintain a 70ºF leaving water temperature when weather permits, floating up to leaving water temperature at design conditions.

The baseline building design condenser water pump power shall be 19 W/gpm. Each chiller shall be modeled with separate condenser water and chilled water pumps interlocked to operate with the associated chiller.

Supply Air Temperature Reset (§ G3.1.3.12)
For baseline building systems 5 through 8 (all VAV systems), the supply air temperature shall be reset higher by 5°F under minimum load conditions.

VAV Minimum Flow Set Points (§ G3.1.3.13)
For baseline building systems 5 and 7 (both conventional VAV systems), the minimum volume set points for VAV reheat boxes shall be 0.4 cfm/ft² of floor area served or the minimum ventilation rate, whichever is larger. The simulation model for the baseline building shall include this air volume as the minimum to be delivered to the space during occupied periods and reheating of the cool air shall not occur until air has been reduced to this minimum, but the box may open up further for heating under high heating loads.

Fan Power (§ G3.1.3.14)
For systems 6 and 8 (both parallel fan powered VAV systems), the terminal box fans shall be sized for 50% of the peak design flow rate and shall be modeled with a fan power of 0.35 W/cfm. Simulation models for the baseline building shall include a minimum volume set points for the parallel fan-powered boxes to be equal to 30% of peak design flow rate or the rate required to meet the minimum outdoor air ventilation requirement, whichever is larger. The supply air temperature set point shall be constant at the design condition.

VAV Fan Part-Load Performance (§ G3.1.3.15)
For baseline building systems 5 through 8, the principal supply fan shall be modeled with a variable speed drive and the part load performance of the fan shall be fixed according to Table G3.1.3.15 of the Standard. The performance is illustrated in Figure G-G.

Service Hot Water Systems (Table G3.1-11)

Proposed Building Service Hot-Water Systems
The building performance rating method requires that service hot water systems be included in the overall building performance and sets a specific baseline. This provides an opportunity for credit toward the proposed building to baseline building margin.

Service hot water systems are treated similarly to the HVAC systems discussed previously. The basic rule is that the proposed design hot-water system is modeled in accordance with the design documents, including equipment types, capacities, efficiencies, insulation, controls, and all other related performance parameters. In cases where a service hot-water system already exists, the proposed building model must be based on that system's characteristics.

If the proposed building has service water heating loads, but the system has not been designed, then the proposed building shall have the same system as the baseline building, which is described later in this chapter.

Where the actual hot water loads are not known, it is acceptable to use the values in Table G-B.

If the proposed building has no service water heating loads, then no system is modeled.

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Baseline Building Service Hot-Water Systems

In general, the service hot water system in the baseline building shall comply with the mandatory measures and prescriptive requirements specified in Chapter 7 of the Standard. The baseline building water heating system shall use the same energy source as the proposed building, if the proposed building uses electric water heaters, then so should the baseline building. The baseline building service water heating system shall meet the minimum efficiency requirements specified in § 7.2.2 of the Standard.

Not all nonresidential buildings have service hot water systems. In the extremely rare case that the proposed building does not include a service water heating system and, based on the occupancy of the proposed building, there is no service hot water load, then no service hot water system shall be modeled in the baseline building or the proposed building.

If an addition is being rated with consideration of the existing portion of the building and the existing building has a water heater that will continue to be used for the existing building, the addition or both, then the baseline building service water heating system shall reflect the actual system type using actual component capacities and efficiencies of the existing system.

In the case where the proposed building does not include a service water heating system, but based on the occupancy of the proposed building, the building has service water loads, then an electric resistance electric water heating system shall be used for both the baseline building and the proposed building that meets the minimum efficiency requirements of § 7.2.2. An identical system shall be used for both the proposed building and the baseline building so that there is no benefit or penalty in the building performance rating.

When the proposed building includes a single system for both space heating and service water heating, the baseline building shall use separate systems meeting the minimum efficiency requirements applicable to each system individually.

When the prescriptive requirements of § 6.3.6.2 require that heat be recovered

Table G-B—Acceptable Occupant Densities, Receptacle Power Densities, and Service Hot Water Consumption[1]

Building Type	Occupancy Density[2] ft²/Person (Btu/h · ft²)	Receptacle Power Density[3] Watts/ ft² (Btu/h · ft²)	Service Hot Water Quantities[4] Btu/h · Person
Assembly	50 (4.60)	0.25 (0.85)	215
Health/Institutional	200 (1.15)	1.00 (3.41)	135
Hotel/Motel	250 (0.92)	0.25 (0.85)	1,110
Light Manufacturing	750 (0.31)	0.20 (0.68)	225
Office	275 (0.84)	0.75 (2.56)	175
Parking Garage	NA	NA	NA
Restaurant	100 (2.30)	0.10 (0.34)	390
Retail	300 (0.77)	0.25 (0.85)	135
School	75 (3.07)	0.50 (1.71)	215
Warehouse	15,000 (0.02)	0.10 (0.34)	225

1. *The occupancy densities, receptacle power densities, and service hot water consumption values are from ASHRAE* Standard 90.1-1989 *and addenda.*
2. *Values are in square feet of conditioned floor area per person. Heat generation in Btu per person per hour is 230 sensible and 190 latent. Figures in parenthesis are equivalent Btu per hour per square foot.*
3. *Values are in Watts per square foot of conditioned floor area. Figures in parenthesis are equivalent Btu per hour per square foot. These values are the minimum acceptable. If other process loads are not input (such as for computers, cooking, refrigeration, etc.), it is recommended that receptacle power densities be increased until total process energy consumption is equivalent to 25% of the total.*
4. *Values are in Btu per person per hour.*

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from air conditioning condensers, then the baseline building shall include condenser heat recovery, without consideration of the exceptions to 6.3.6.2. This requirement applies to 24-hour facilities like hotels that have a peak service water heating load of 1,000,000 Btu/h or more and the heat rejection system (cooling tower) has a capacity of 6,000,000 Btu/h or more. The heat recovery system shall have the capability to either preheat the service hot water to at least 85 ºF or to recover at least 60% of the peak heat rejection load at design conditions.

If the simulation program is not capable of modeling a condenser heat recovery system, then the proposed building shall be designed to meet the prescriptive requirements in accordance with § 6.5.6.2, and no heat-recovery system shall be included in either the proposed building or the baseline building.

When recirculation pumps are used to ensure prompt availability of service water at the end use, the energy consumption of such pumps shall be calculated explicitly.

The baseline building service water loads and usage shall be the same as those of the proposed building and shall be documented by the calculation procedures described in Section 7.2.1, with the following exceptions:

- Service hot water usage can be demonstrated to be reduced by documented water conservation measures that reduce the physical volume of service water required. Examples include low flow shower heads. Such reduction shall be demonstrated by calculations.
- Service hot water energy consumption can be demonstrated to be reduced by reducing the required temperature of service mixed water or by increasing the temperature of the entering make-up water. Examples include alternative sanitizing technologies for dishwashing or heat recovery to entering makeup water. Such reduction shall be demonstrated by calculations.
- Service hot water usage can be demonstrated to be reduced by reducing the hot fraction of mixed water to achieve required operational temperature. Examples include shower or laundry heat recovery to incoming cold water supply, reducing the hot water fraction required to meet required mixed water temperature. Such reduction shall be demonstrated by calculations.

Mandatory Provisions

For service water heating, the mandatory provisions are described in § 7.4. Some mandatory provisions worth highlighting are:

- Minimum service water heating equipment (§ 7.4.2, exception to 7.4.2);
- Pipe insulation (§ 7.4.3);
- Controls (§ 7.4.4);
- Pool covers (§ 7.4.5.2, exception to 7.4.5.2);
- Heat traps (§ 7.4.6).

Again, remember that these mandatory provisions cannot be traded off.

Receptacle and other Loads (Table G3.1-12)

Receptacle and Process Loads

Receptacle and process loads shall be estimated based on the building type of the proposed building or individual space types within the proposed building. These shall be included in the energy models for both the proposed building and the baseline building. These loads shall be the same for both the proposed building and the baseline building unless the rating authority had a procedure and method for crediting measures in the proposed building aimed at reducing receptacle energy.

Examples of receptacle loads include personal computers, copy machines, appliances in kitchens, printers, fax machines, and any type of specialized equipment for specific building types, e.g. cooking equipment in restaurants, refrigerated casework in supermarkets and convenience stores, and specialized machinery in shops.

It is anticipated that most receptacle and process energy will be the same for both the proposed building and the baseline building. Rating authorities may, however, offer credit for the purchase of Energy STAR appliances and other equipment for which there is a performance rating.

Where the actual receptacle loads are not known, it is acceptable to use the values in Table G-B.

Systems that do not interact substantially with other energy systems, such as elevators or parking garage fans, should also be included, but may be estimated separately and added to the results of the energy simulation model.

Other Baseline Systems

For motors, the baseline building must comply with the minimum efficiency requirements in § 10.4.1. Credit can be taken in the proposed building for motors with higher efficiencies. The building performance rating method generally does not allow credit for non-HVAC motors or for other miscellaneous energy-related equipment in a building where no efficiency requirements exist in the Standard, such as elevators, conveyors, autoclaves, etc., unless specifically approved by the rating authority. Variations of the power requirements, schedules or control sequences of the equipment modeled in the baseline building from those in the proposed design may be allowed by the rating authority based upon documentation that the equipment installed in the proposed design represent a significant verifiable departure from documented conventional

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practice. The burden of this documentation is to demonstrate that accepted conventional practice would result in baseline building equipment different from those installed in the proposed design. Occupancy and occupancy schedules may not be changed.

For power distribution systems, the mandatory provisions are in § 8.4. For motors, the mandatory provisions are in § 10.4.1. Some mandatory provisions worth highlighting are:

- Feeders are allowed a maximum voltage drop of 2% (§ 8.4.1.1);
- Completion requirements (§ 8.7.1, § 8.7.2);
- Minimum motor efficiency requirements (§ 10.4.1).

Modeling Limitations to the Simulation Program (Table G3.1-13)

In general, all the energy systems of the proposed design must be included in the simulation model. However, in cases where the simulation program lacks modeling capabilities needed to fully model a component or system of the proposed design, the energy analyst may use a model that is thermodynamically equivalent. Making adjustments to lighting schedules to account for the benefits of daylighting is one example. Elevating the space temperature in the proposed building to account for temperature stratification in thermal displacement and under floor air distribution systems is another.

Good engineering judgment is required and to model the component or system using a thermodynamically similar model that is within the capabilities of the program being used. The energy analyst shall thoroughly understand the algorithms of the simulation program and the thermodynamic characteristics of the component being modeled. In many cases, this can be accomplished without compromising accuracy.

If a reasonable calculation of the proposed building performance rating cannot be made, then the best solution is to seek a different program that has the needed capabilities.

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Case Study

To illustrate how to use the Appendix G Performance Rating Method, this case study reviews the step-by-step procedures followed for the same example building described in the ECB Case Study. These steps are:

1. Contact the rating authority.
2. Comply with the Mandatory Requirements of § 5.4, § 6.4, § 7.4, § 8.4, § 9.4, and § 10.4.
3. Create the proposed building simulation model.
4. Create the baseline building simulation model.
5. Fine-tune the models.
6. Document performance rating.

Building Description

The building in this case study is exactly the same as that used in the ECB Case Study. Please refer to that section in Chapter 11 of this Manual for details.

Step 1: Contact the Local Rating Authority

Before using the Appendix G Performance Rating Method for a building, it's important to confirm that the rating authority has approved the use of the method. Questions to ask of the authority include:

- Is the ANSI/ASHRAE/IESNA 90.1-2007 Appendix G Performance Rating Method accepted for showing a proposed design building having better energy performance than the baseline building?
- Have there been any amendments?
- Are there any special limitations or requirements on the use of the Appendix G?
- Are there simulation programs that must be used?
- What climatic data are approved for use in the energy simulations?
- What utility rates are approved for calculating energy costs?

Step 2: Comply With the Mandatory Provisions

Both the baseline building design and the simulation used in the Appendix G method must comply with these requirements. See the technical chapters of this Manual (chapters 5, 6, 7, 8, 9, and 10) for details about the Standard's Mandatory Requirements. These features must be included in the design documents.

Step 3: Create the Proposed Building Simulation Model

The simulation model of the proposed design shall be consistent with the design documents, including proper accounting of fenestration and opaque envelope types and areas; interior lighting power and controls; HVAC system types, sizes, and controls; and service water heating systems and controls. All end-use load components within and associated with the building shall be modeled, including, but not limited to, exhaust fans, parking garage ventilation fans, snow-melt and freeze-protection equipment, facade lighting, swimming pool heaters and pumps, elevators and escalators, refrigeration, and cooking.

For this case study, the proposed building is the almost same as the proposed building in the ECB Case Study in Chapter 11 of this Manual, except with no manually operated interior shades or blinds.

Step 4: Create the Baseline Building Simulation Model

The simulation model of the baseline building is created by modifying the building envelope, fenestrations, lighting, HVAC systems, and central heating/cooling plant of the proposed building. If a computer program is certified by the rating authority for the performance rating method, the program will automatically generate a baseline building model from the inputs for the proposed building model. If no such program is available, then you should use the procedure for creating the baseline building that is described in Appendix G of the Standard.

The details below illustrate how to manually create the sample baseline building model. To determine the characteristics of the baseline building, fill out a set of the Standard's compliance forms, but replace the actual characteristics of the proposed building with the minimally compliant values specified in Appendix G. Where there is no guidance from the Appendix G about which values should be used, then model the baseline building with values identical to the proposed building. For example, in this case study, there is no requirement for the lighting power density in dwelling units (see exception (b) to § 9.1); therefore, the lighting power in the living spaces will be identical in both models.

Space Conditioning Categories

The baseline building and the proposed building have the same space use classification.

- *Residential Spaces*: the dwelling units on the apartment levels.
- *Nonresidential Spaces*: office and retail spaces as well as nondwelling space on apartment levels (e.g., hallways).

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- *Unconditioned Spaces*: stairs and parking garage.

Walls

There are five wall types in the proposed building design. Three of these are considered either exterior or semi-exterior building envelope and are covered by requirements in the Standard. The other two wall types, exterior unconditioned and interior partitions, are not covered by the Standard and are identical in the baseline and proposed design. These five wall types are described below:

- *Nonresidential Exterior:* walls between the conditioned nonresidential spaces (including apartment hallways) and the outside.
- *Residential Exterior:* walls between the conditioned space of the dwelling units and the outside. Note that the wall of the parking garage is considered exterior because the garage must be ventilated—either by natural or forced ventilation—to remove contaminants.
- *Semi-Exterior:* walls between enclosed conditioned areas and unconditioned areas (for example, walls adjacent to the unheated stairwell). Semi-exterior walls are treated as exteriors for semiheated zones.
- *Unconditioned Exterior:* there are no compliance requirements for unconditioned exterior walls. These wall properties will be the same in the baseline and proposed building models.
- *Interior Partitions:* walls between two conditioned zones. In general, there is little heat transfer through interior partitions unless operating schedules are markedly different. The Standard has no compliance requirements for interior partition walls, so these wall properties will be the same in the baseline and proposed building models.

The baseline building is modeled with no self-shading. The baseline building above-grade exterior walls are modeled as steel-framed constructions with U-factor of 0.124 Btu/h-ft²-°F for nonresidential spaces and U-factor of 0.084 Btu/h-ft²-°F for residential spaces, based on the envelope criteria Table 5.5-3 for climate zone 3A.

Walls are rotated accordingly for the four baseline simulation runs with the baseline building rotated 0, 90, 180, and 270 degrees.

Windows

There are different requirements for windows depending on the frame type. Window and wall areas for residential and nonresidential must be calculated separately (see § 5.3.2). Table G-C compares the proposed and baseline glazing properties.

Overhangs are not in the baseline building model.

In this case study, the baseline building has the same windows geometry as the proposed building.

Lighting

The baseline building lighting system can be calculated using either the building area method or the space-by-space method. The building area method requires fewer inputs (see Table 9.5.1 of the Standard). For simplicity's sake, this is the method used in this case study. If the building area method is used, it must be used throughout the whole project.

Table G-C—Comparison of Proposed and Budget Window Solar Heat Gain Coefficients

Space Category	Orientation	Above-Grade Wall Area	Window Area	Window-Wall-Ratio	Proposed U-factor/SHGC	Budget U-factor/SHGC
Residential	North	6,600	1,202	18%	1.22/0.82	0.65/0.25
	Non-North	30,360	5,389		1.22/0.82	0.65/0.25
Nonresidential				37%		
Retail	North	1,600	534		1.22/0.82	0.65/0.25
Office	North	3,200	1,000		1.22/0.82	0.65/0.25
Retail	Non-North	4,293	2,920		1.22/0.82	0.65/0.25
Office	Non-North	8,587	2,054		1.22/0.82	0.65/0.25
Nonresidential Total		17,680	6,508			

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Table G-D compares the proposed and baseline lighting power densities for the different spaces.

Even though the parking garage is considered unconditioned and unenclosed, it is still an interior space for lighting purposes and is available for lighting power trade-offs with the rest of the building. Note that the multi-family hallway is considered separately from the apartments. The hallway is considered a nonresidential space with limitations on lighting power. The dwelling units inside the building are exempt from lighting power density requirements and thus the proposed design wattage and baseline lighting wattage are identical.

The baseline building does not have daylight dimming controls for the office spaces.

Mechanical

Defining the Mechanical System
The type of mechanical system used in the baseline building is based upon the following evaluation of the systems in the proposed building. To define the air-handling systems for the baseline building, answer the following four questions and consult Tables G3.1.1A and G3.1.1B.

- Is the building for residential or nonresidential use?
- How many floors does the building have?
- What is the total conditioned floor area of the building?
- Is the heating source fossil fuel, fossil/electric hybrid, purchased heat, or electric and other?

In the proposed building, there are four stories of residential area and four stories of nonresidential area, both with conditioned floor area more than 20,000 ft². The nonresidential area has a total floor area of 54,000 ft², which is between 25,000 ft² and 150,000 ft². The heating source is a natural gas boiler. Therefore, system 1 – PTAC (Packaged Terminal Air-Conditioner) is selected to serve each dwelling unit in the residential area; while system 5 - Packaged VAV (with VSD fan) with Hot Water Reheat is selected to serve the office and retail areas. The parking garage is ventilated only and is served by the same system defined in the proposed building.

Table G-D—Comparison of Proposed and Baseline Lighting Power

		Proposed		Baseline	
Space Description	Area	Watts	LPD	Watts	LPD
Parking	16,000	4,000	0.25	4,800	0.30
Retail	11,000	15,180	1.38	16,950	1.50
Office	27,000	31,320	1.16	27,000	1.00
Apartment units	43,600	71,940	1.65	71,940	1.65
Multi-family hallway	5,600	4,480	0.80	3,920	0.70
Totals	103,200	126,920	1.23	124,520	1.21

Economizer
Although the proposed building has an air economizer for systems serving the office spaces, the Dallas climate (zone 3A) does not require an economizer for the baseline building (see Table G3.1.2.6A).

Fans
The fans in the baseline building's HVAC systems have rated electric power based on Table G3.1.2.9 and formula defined in G3.1.2.9. The proposed building is allowed to get credit for lower fan energy use.

Exhaust Air Energy Recovery
No exhaust air energy recovery is used in the baseline building as no HVAC systems require more than 70% of outdoor air.

Hot Water Pumps
The baseline building has primary only hot water loop with continuous variable flow by constant speed pump consuming power of 19 W/gpm. The hot water deltaT is set to 50°F (with supply of 180°F and return of 130°F).

Controls
All systems in the building have setback thermostats. The temperature schedules reflect that they are used to turn off commercial fan systems during unoccupied hours and to set back the residential temperatures at night. Since the office and retail systems have airflow rates in excess of 10,000 cfm, the baseline building model of these HVAC systems includes optimal start control. The minimum setpoint of the VAV boxes for the office and retail systems are set to 0.4 cfm/ft². The office and retail systems have cooling supply air

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temperature reset higher by 5°F under the minimum cooling load conditions.

Cooling and Heating Equipment Sizing
The baseline building HVAC systems are oversized 15% for cooling and 25% for heating. There is no chiller in the baseline building. The boiler plant is serving a conditioned floor area of more than 15,000 ft², therefore two equally sized boilers each with rated heating capacity of 750,000 Btu/h are used.

Cooling and Heating Equipment Efficiency
The direct expansion cooling equipment for the baseline building has EER set to Table 6.2.1A for the office and retail systems, and to Table 6.2.1D for the residential systems. The EER is adjusted in the simulations to separately calculate the fan energy use. The boiler has a thermal efficiency of 75%.

Sizing Calculations
The baseline building simulation does sizing calculations for each of the four orientations when the building is rotated.

Other Uses
When using the performance rating method, all of the energy consumption in the building must be accounted for. This may introduce components that were not included in the ECB analysis.

Defining the Elevator System
The elevator system used in the baseline building is the same as that of the proposed building.

Defining the Kitchen Cooking System
The kitchen cooking system used in the baseline building is the same as that of the proposed building.

Defining the Kitchen Refrigeration System
The kitchen refrigeration system used in the baseline building is the same as that of the proposed building.

Step 5: Fine-Tune the Models

After both models have been run, the results are analyzed to check for errors and to verify performance. In some cases, unmet load warnings will indicate the number of hours that the system or plant was unable to meet the loads placed on them. This is commonly found in morning start-up situations where the pick-up loads cannot be met in a single hour.

If the number of hours that loads are unmet by either the systems or plant of either the baseline or the proposed model exceeds 300 hours of the 8760 hours simulated, or differs by more than 50 hours between the two models, these simulation results will not be accepted as valid. The best way to deal with this problem is to adjust the sizing of either the baseline or the proposed HVAC systems. As shown on the sample Performance Rating report, there are no load unmet hours for both models for this case study.

The baseline building is simulated four times with the building rotated 0, 90, 180 and 270 degrees. The baseline energy performance is the average of the four simulation results.

Both the proposed and the baseline building simulations are using the Texas utility rates from Table G-H Commercial Sector Average Energy Costs by State.

Step 6: Document Performance Rating

The two-page Performance Rating report summarizes the finding that the proposed Dallas building would have lower energy costs than a Standard 90.1-2007 baseline building.
A written description of those energy features that either exceed the minimal requirements or that are less than the requirements must be documented.
The performance rating must be based on the latest proposed building design. If there are any changes in the proposed building, both the proposed building and the baseline building must be updated and re-run.

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Table G-E—Assembly Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	0	0	0	5	5	5	Off	Off	Off	0	0	0	0	0	0
2 (1-2 am)	0	0	0	5	5	5	Off	Off	Off	0	0	0	0	0	0
3 (2-3 am)	0	0	0	5	5	5	Off	Off	Off	0	0	0	0	0	0
4 (3-4 am)	0	0	0	5	5	5	Off	Off	Off	0	0	0	0	0	0
5 (4-5 am)	0	0	0	5	5	5	Off	Off	Off	0	0	0	0	0	0
6 (5-6 am)	0	0	0	5	5	5	On	Off	Off	0	0	0	0	0	0
7 (6-7 am)	0	0	0	40	5	5	On	On	On	0	0	0	0	0	0
8 (7-8 am)	0	0	0	40	30	30	On	On	On	0	0	0	0	0	0
9 (8-9 am)	20	20	10	40	30	30	On	On	On	0	0	0	0	0	0
10 (9-10 am)	20	20	10	75	50	30	On	On	On	5	5	5	0	0	0
11 (10-11 am)	20	20	10	75	50	30	On	On	On	5	5	5	0	0	0
12 (11-12 pm)	80	60	10	75	50	30	On	On	On	35	20	10	0	0	0
13 (12-1 pm)	80	60	10	75	50	65	On	On	On	5	0	0	0	0	0
14 (1-2 pm)	80	60	70	75	50	65	On	On	On	5	0	0	0	0	0
15 (2-3 pm)	80	60	70	75	50	65	On	On	On	5	0	0	0	0	0
16 (3-4 pm)	80	60	70	75	50	65	On	On	On	5	0	0	0	0	0
17 (4-5 pm)	80	60	70	75	50	65	On	On	On	5	0	0	0	0	0
18 (5-6 pm)	80	60	70	75	50	65	On	On	On	0	0	0	0	0	0
19 (6-7 pm)	20	60	70	75	50	65	On	On	On	0	0	0	0	0	0
20 (7-8 pm)	20	60	70	75	50	65	On	On	On	0	65	65	0	0	0
21 (8-9 pm)	20	60	70	75	50	65	On	On	On	0	30	30	0	0	0
22 (9-10 pm)	20	80	70	75	50	65	On	On	On	0	0	0	0	0	0
23 (10-11 pm)	10	10	20	25	50	5	On	On	On	0	0	0	0	0	0
24 (11-12 am)	0	0	0	5	5	5	Off	Off	Off	0	0	0	0	0	0
Total/Day	710	750	700	1155	800	845	1800	1700	1700	70	125	115	0	0	0
Total/Week			50.50 hours			74.20 hours			124 hours			5.9 hours			0 hours
Total/Year			2633 hours			3869 hours			6465 hours			308 hours			0 hours

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-F—Health Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	0	0	0	10	10	5	On	On	On	1	1	1	0	0	0
2 (1-2 am)	0	0	0	10	10	5	On	On	On	1	1	1	0	0	0
3 (2-3 am)	0	0	0	10	10	5	On	On	On	1	1	1	0	0	0
4 (3-4 am)	0	0	0	10	10	5	On	On	On	1	1	1	0	0	0
5 (4-5 am)	0	0	0	10	10	5	On	On	On	1	1	1	0	0	0
6 (5-6 am)	0	0	0	10	10	5	On	On	On	1	1	1	0	0	0
7 (6-7 am)	0	0	0	10	10	5	On	On	On	1	1	1	0	0	0
8 (7-8 am)	10	10	0	50	20	5	On	On	On	17	1	1	2	2	0
9 (8-9 am)	50	30	5	90	40	10	On	On	On	58	20	1	75	46	2
10 (9-10 am)	80	40	5	90	40	10	On	On	On	66	28	1	100	70	2
11 (10-11 am)	80	40	5	90	40	10	On	On	On	78	30	1	100	70	2
12 (11-12 pm)	80	40	5	90	40	10	On	On	On	82	30	1	100	70	2
13 (12-1 pm)	80	40	5	90	40	10	On	On	On	71	24	1	75	51	2
14 (1-2 pm)	80	40	5	90	40	10	On	On	On	82	24	1	100	51	2
15 (2-3 pm)	80	40	5	90	40	10	On	On	On	78	23	1	100	51	2
16 (3-4 pm)	80	40	5	90	40	10	On	On	On	74	23	1	100	51	2
17 (4-5 pm)	80	40	0	30	40	5	On	On	On	63	23	1	100	51	0
18 (5-6 pm)	50	10	0	30	40	5	On	On	On	41	10	1	100	25	0
19 (6-7 pm)	30	10	0	30	10	5	On	On	On	18	1	1	52	2	0
20 (7-8 pm)	30	0	0	30	10	5	On	On	On	18	1	1	52	0	0
21 (8-9 pm)	20	0	0	30	10	5	On	On	On	18	1	1	52	0	0
22 (9-10 pm)	20	0	0	30	10	5	On	On	On	10	1	1	28	0	0
23 (10-11 pm)	0	0	0	30	10	5	On	On	On	1	1	1	0	0	0
24 (11-12 am)	0	0	0	10	10	5	On	On	On	1	1	1	0	0	0
Total/Day	850	380	40	1060	550	160	2400	2400	2400	783	249	24	1136	540	16
Total/Week			46.70 hours			60.10 hours			168 hours			41.88 hours			62.36 hours
Total/Year			2435 hours			3134 hours			8760 hours			2148 hours			3251 hours

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-G—Hotel/Motel Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	90	90	70	20	20	30	On	On	On	20	20	25	40	44	55
2 (1-2 am)	90	90	70	15	20	30	On	On	On	15	15	20	33	35	55
3 (2-3 am)	90	90	70	10	10	20	On	On	On	15	15	20	33	35	43
4 (3-4 am)	90	90	70	10	10	20	On	On	On	15	15	20	33	35	43
5 (4-5 am)	90	90	70	10	10	20	On	On	On	20	20	20	33	35	43
6 (5-6 am)	90	90	70	20	10	20	On	On	On	25	25	30	33	35	43
7 (6-7 am)	70	70	70	40	30	30	On	On	On	50	40	50	42	40	52
8 (7-8 am)	40	50	70	50	30	40	On	On	On	60	50	50	42	32	52
9 (8-9 am)	40	50	50	40	40	40	On	On	On	55	50	50	52	45	65
10 (9-10 am)	20	30	50	40	40	30	On	On	On	45	50	55	52	45	65
11 (10-11 am)	20	30	50	25	30	30	On	On	On	40	45	50	40	42	53
12 (11-12 pm)	20	30	30	25	25	30	On	On	On	45	50	50	51	60	60
13 (12-1 pm)	20	30	30	25	25	30	On	On	On	40	50	40	51	65	53
14 (1-2 pm)	20	30	20	25	25	20	On	On	On	35	45	40	51	65	51
15 (2-3 pm)	20	30	20	25	25	20	On	On	On	30	40	30	51	65	50
16 (3-4 pm)	30	30	20	25	25	20	On	On	On	30	40	30	51	65	44
17 (4-5 pm)	50	30	30	25	25	20	On	On	On	30	35	30	63	65	64
18 (5-6 pm)	50	50	40	25	25	20	On	On	On	40	40	40	80	75	62
19 (6-7 pm)	50	60	40	60	60	50	On	On	On	55	55	50	86	80	65
20 (7-8 pm)	70	60	60	80	70	70	On	On	On	60	55	50	70	80	63
21 (8-9 pm)	70	60	60	90	70	80	On	On	On	50	50	40	70	75	63
22 (9-10 pm)	80	70	80	80	70	60	On	On	On	55	55	50	70	75	63
23 (10-11 pm)	90	70	80	60	60	50	On	On	On	45	40	40	45	55	40
24 (11-12 am)	90	70	80	30	30	30	On	On	On	25	30	20	45	55	40
Total/Day	1390	1390	1300	855	785	810	2400	2400	2400	915	930	900	1217	1303	1287
Total/Week			96.40 hours			58.70 hours			168.0 hours			64.05 hours			86.75 hours
Total/Year			5026 hours			3061 hours			8760 hours			3340 hours			4523 hours

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-H—Light Manufacturing Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
2 (1-2 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
3 (2-3 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
4 (3-4 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
5 (4-5 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
6 (5-6 am)	0	0	0	10	5	5	Off	Off	Off	8	8	7	0	0	0
7 (6-7 am)	10	10	5	10	10	5	On	On	Off	7	7	4	0	0	0
8 (7-8 am)	20	10	5	30	10	5	On	On	Off	19	11	4	35	16	0
9 (8-9 am)	95	30	5	90	30	5	On	On	Off	35	15	4	69	14	0
10 (9-10 am)	95	30	5	90	30	5	On	On	Off	38	21	4	43	21	0
11 (10-11 am)	95	30	5	90	30	5	On	On	Off	39	19	4	37	18	0
12 (11-12 pm)	95	30	5	90	30	5	On	On	Off	47	23	6	43	25	0
13 (12-1 pm)	50	10	5	80	15	5	On	On	Off	57	20	6	58	21	0
14 (1-2 pm)	95	10	5	90	15	5	On	On	Off	54	19	9	48	13	0
15 (2-3 pm)	95	10	5	90	15	5	On	On	Off	34	15	6	37	8	0
16 (3-4 pm)	95	10	5	90	15	5	On	On	Off	33	12	4	37	4	0
17 (4-5 pm)	95	10	5	90	15	5	On	On	Off	44	14	4	46	5	0
18 (5-6 pm)	30	5	5	50	5	5	On	On	Off	26	7	4	62	6	0
19 (6-7 pm)	10	5	0	30	5	5	On	Off	Off	21	7	4	20	0	0
20 (7-8 pm)	10	0	0	30	5	5	On	Off	Off	15	7	4	12	0	0
21 (8-9 pm)	10	0	0	20	5	5	On	Off	Off	17	7	4	4	0	0
22 (9-10 pm)	10	0	0	20	5	5	On	Off	Off	8	9	7	4	0	0
23 (10-11 pm)	5	0	0	10	5	5	Off	Off	Off	5	5	4	0	0	0
24 (11-12 am)	5	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
Total/Day	920	200	60	1040	280	120	1600	1200	0	537	256	113	555	151	0
Total/Week			48.60 hours			56.00 hours			92.00 hours			30.54 hours			29.26 hours
Total/Year			2534 hours			2920 hours			4797 hours			1592 hours			1526 hours

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-I—Office Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
2 (1-2 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
3 (2-3 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
4 (3-4 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
5 (4-5 am)	0	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
6 (5-6 am)	0	0	0	10	5	5	Off	Off	Off	8	8	7	0	0	0
7 (6-7 am)	10	10	5	10	10	5	On	On	Off	7	7	4	0	0	0
8 (7-8 am)	20	10	5	30	10	5	On	On	Off	19	11	4	35	16	0
9 (8-9 am)	95	30	5	90	30	5	On	On	Off	35	15	4	69	14	0
10 (9-10 am)	95	30	5	90	30	5	On	On	Off	38	21	4	43	21	0
11 (10-11 am)	95	30	5	90	30	5	On	On	Off	39	19	4	37	18	0
12 (11-12 pm)	95	30	5	90	30	5	On	On	Off	47	23	6	43	25	0
13 (12-1 pm)	50	10	5	80	15	5	On	On	Off	57	20	6	58	21	0
14 (1-2 pm)	95	10	5	90	15	5	On	On	Off	54	19	9	48	13	0
15 (2-3 pm)	95	10	5	90	15	5	On	On	Off	34	15	6	37	8	0
16 (3-4 pm)	95	10	5	90	15	5	On	On	Off	33	12	4	37	4	0
17 (4-5 pm)	95	10	5	90	15	5	On	On	Off	44	14	4	46	5	0
18 (5-6 pm)	30	5	5	50	5	5	On	On	Off	26	7	4	62	6	0
19 (6-7 pm)	10	5	0	30	5	5	On	Off	Off	21	7	4	20	0	0
20 (7-8 pm)	10	0	0	30	5	5	On	Off	Off	15	7	4	12	0	0
21 (8-9 pm)	10	0	0	20	5	5	On	Off	Off	17	7	4	4	0	0
22 (9-10 pm)	10	0	0	20	5	5	On	Off	Off	8	9	7	4	0	0
23 (10-11 pm)	5	0	0	10	5	5	Off	Off	Off	5	5	4	0	0	0
24 (11-12 am)	5	0	0	5	5	5	Off	Off	Off	5	5	4	0	0	0
Total/Day	920	200	60	1040	280	120	1600	1200	0	537	256	113	555	151	0
Total/Week			48.60 hours			56.00 hours			92.00 hours			30.54 hours			29.26 hours
Total/Year			2534 hours			2920 hours			4797 hours			1592 hours			1526 hours

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-J—Parking Garage Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)				100	100	100									
2 (1-2 am)				100	100	100									
3 (2-3 am)				100	100	100									
4 (3-4 am)				100	100	100									
5 (4-5 am)				100	100	100									
6 (5-6 am)				100	100	100									
7 (6-7 am)				100	100	100									
8 (7-8 am)				100	100	100									
9 (8-9 am)				100	100	100									
10 (9-10 am)				100	100	100									
11 (10-11 am)				100	100	100									
12 (11-12 pm)	NA			100	100	100	Based on likely use			NA			Included with other occupancies		
13 (12-1 pm)				100	100	100									
14 (1-2 pm)				100	100	100									
15 (2-3 pm)				100	100	100									
16 (3-4 pm)				100	100	100									
17 (4-5 pm)				100	100	100									
18 (5-6 pm)				100	100	100									
19 (6-7 pm)				100	100	100									
20 (7-8 pm)				100	100	100									
21 (8-9 pm)				100	100	100									
22 (9-10 pm)				100	100	100									
23 (10-11 pm)				100	100	100									
24 (11-12 am)				100	100	100									
Total/Day				2400	2400	2400									
Total/Week						168 hours									
Total/Year						8760 hours									

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-K—Restaurant Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	15	30	20	15	20	20	On	On	On	20	20	25	0	0	0
2 (1-2 am)	15	25	20	15	15	15	On	On	On	15	15	20	0	0	0
3 (2-3 am)	5	5	5	15	15	15	On	On	On	15	15	20	0	0	0
4 (3-4 am)	0	0	0	15	15	15	Off	Off	Off	0	0	0	0	0	0
5 (4-5 am)	0	0	0	15	15	15	Off	Off	Off	0	0	0	0	0	0
6 (5-6 am)	0	0	0	20	15	15	Off	Off	Off	0	0	0	0	0	0
7 (6-7 am)	0	0	0	40	30	30	Off	Off	Off	0	0	0	0	0	0
8 (7-8 am)	5	0	0	40	30	30	On	Off	Off	60	0	0	0	0	0
9 (8-9 am)	5	0	0	60	60	50	On	Off	Off	55	0	0	0	0	0
10 (9-10 am)	5	5	0	60	60	50	On	On	Off	45	50	0	0	0	0
11 (10-11 am)	20	20	10	90	80	70	On	On	On	40	45	50	0	0	0
12 (11-12 pm)	50	45	20	90	80	70	On	On	On	45	50	50	0	0	0
13 (12-1 pm)	80	50	25	90	80	70	On	On	On	40	50	40	0	0	0
14 (1-2 pm)	70	50	25	90	80	70	On	On	On	35	45	40	0	0	0
15 (2-3 pm)	40	35	15	90	80	70	On	On	On	30	40	30	0	0	0
16 (3-4 pm)	20	30	20	90	80	70	On	On	On	30	40	30	0	0	0
17 (4-5 pm)	25	30	25	90	80	60	On	On	On	30	35	30	0	0	0
18 (5-6 pm)	50	30	35	90	90	60	On	On	On	40	40	40	0	0	0
19 (6-7 pm)	80	70	55	90	90	60	On	On	On	55	55	50	0	0	0
20 (7-8 pm)	80	90	65	90	90	60	On	On	On	60	55	50	0	0	0
21 (8-9 pm)	80	70	70	90	90	60	On	On	On	50	50	40	0	0	0
22 (9-10 pm)	50	65	35	90	90	60	On	On	On	55	55	50	0	0	0
23 (10-11 pm)	35	55	20	50	50	50	On	On	On	45	40	40	0	0	0
24 (11-12 am)	20	35	20	30	30	30	On	On	On	25	30	20	0	0	0
Total/Day	750	740	485	1455	1365	1115	2000	1800	1700	790	730	625	0	0	0
Total/Week			49.75 hours			97.55 hours			135 hours			53.05 hours			0 hours
Total/Year			2594 hours			5086 hours			7039 hours			2766 hours			0 hours

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-L—Retail Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	0	0	0	5	5	5	Off	Off	Off	4	11	7	0	0	0
2 (1-2 am)	0	0	0	5	5	5	Off	Off	Off	5	10	7	0	0	0
3 (2-3 am)	0	0	0	5	5	5	Off	Off	Off	5	8	7	0	0	0
4 (3-4 am)	0	0	0	5	5	5	Off	Off	Off	4	6	6	0	0	0
5 (4-5 am)	0	0	0	5	5	5	Off	Off	Off	4	6	6	0	0	0
6 (5-6 am)	0	0	0	5	5	5	Off	Off	Off	4	6	6	0	0	0
7 (6-7 am)	0	0	0	5	5	5	On	On	Off	4	7	7	0	0	0
8 (7-8 am)	10	10	0	20	10	5	On	On	Off	15	20	10	12	9	0
9 (8-9 am)	20	20	0	50	30	10	On	On	On	23	24	12	22	21	0
10 (9-10 am)	50	50	10	90	60	10	On	On	On	32	27	14	64	56	11
11 (10-11 am)	50	60	20	90	90	40	On	On	On	41	42	29	74	66	13
12 (11-12 pm)	70	80	20	90	90	40	On	On	On	57	54	31	68	68	35
13 (12-1 pm)	70	80	40	90	90	60	On	On	On	62	59	36	68	68	37
14 (1-2 pm)	70	80	40	90	90	60	On	On	On	61	60	36	71	69	37
15 (2-3 pm)	70	80	40	90	90	60	On	On	On	50	49	34	72	70	39
16 (3-4 pm)	80	80	40	90	90	60	On	On	On	45	48	35	72	69	41
17 (4-5 pm)	70	80	40	90	90	60	On	On	On	46	47	37	73	66	38
18 (5-6 pm)	50	60	20	90	90	40	On	On	Off	47	46	34	68	58	34
19 (6-7 pm)	50	20	10	60	50	20	On	On	Off	42	44	25	68	47	3
20 (7-8 pm)	30	20	0	60	30	5	On	On	Off	34	36	27	58	43	0
21 (8-9 pm)	30	20	0	50	30	5	On	On	Off	33	29	21	54	43	0
22 (9-10 pm)	0	10	0	20	10	5	Off	On	Off	23	22	16	0	8	0
23 (10-11 pm)	0	0	0	5	5	5	Off	Off	Off	13	16	10	0	0	0
24 (11-12 am)	0	0	0	5	5	5	Off	Off	Off	8	13	6	0	0	0
Total/Day	720	750	280	1115	985	525	1500	1600	900	662	690	459	844	761	288
Total/Week			46.30 hours			70.85 hours			100 hours			44.59 hours			52.69 hours
Total/Year			2414 hours			3694 hours			5214 hours			2325 hours			2747 hours

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-M—School Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	0	0	0	5	5	5	Off	Off	Off	5	3	3	0	0	0
2 (1-2 am)	0	0	0	5	5	5	Off	Off	Off	5	3	3	0	0	0
3 (2-3 am)	0	0	0	5	5	5	Off	Off	Off	5	3	3	0	0	0
4 (3-4 am)	0	0	0	5	5	5	Off	Off	Off	5	3	3	0	0	0
5 (4-5 am)	0	0	0	5	5	5	Off	Off	Off	5	3	3	0	0	0
6 (5-6 am)	0	0	0	5	5	5	Off	Off	Off	5	3	3	0	0	0
7 (6-7 am)	0	0	0	5	5	5	Off	Off	Off	5	3	3	0	0	0
8 (7-8 am)	5	0	0	30	5	5	On	Off	Off	10	3	3	0	0	0
9 (8-9 am)	75	10	0	85	15	5	On	On	Off	34	3	5	30	0	0
10 (9-10 am)	90	10	0	95	15	5	On	On	Off	60	5	5	30	0	0
11 (10-11 am)	90	10	0	95	15	5	On	On	Off	63	5	5	30	0	0
12 (11-12 pm)	80	10	0	95	15	5	On	On	Off	72	5	5	30	0	0
13 (12-1 pm)	80	10	0	80	15	5	On	On	Off	79	5	5	30	0	0
14 (1-2 pm)	80	0	0	80	5	5	On	Off	Off	83	3	5	30	0	0
15 (2-3 pm)	80	0	0	80	5	5	On	Off	Off	61	3	3	30	0	0
16 (3-4 pm)	45	0	0	70	5	5	On	Off	Off	65	3	3	15	0	0
17 (4-5 pm)	15	0	0	50	5	5	On	Off	Off	10	3	3	0	0	0
18 (5-6 pm)	5	0	0	50	5	5	On	Off	Off	10	3	3	0	0	0
19 (6-7 pm)	15	0	0	35	5	5	On	Off	Off	19	3	3	0	0	0
20 (7-8 pm)	20	0	0	35	5	5	On	Off	Off	25	3	3	0	0	0
21 (8-9 pm)	20	0	0	35	5	5	On	Off	Off	22	3	3	0	0	0
22 (9-10 pm)	10	0	0	30	5	5	On	Off	Off	22	3	3	0	0	0
23 (10-11 pm)	0	0	0	5	5	5	Off	Off	Off	12	3	3	0	0	0
24 (11-12 am)	0	0	0	5	5	5	Off	Off	Off	9	3	3	0	0	0
Total/Day	710	50	0	990	170	120	1500	500	0	691	80	84	285	0	0
Total/Week			36.00 hours			52.40 hours			80.00 hours			36.19 hours			14.25 hours
Total/Year			1877 hours			2732 hours			4171 hours			1887 hours			743 hours

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-N—Warehouse Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Receptacle Percent of Maximum Load			Schedule for HVAC System			Schedule for Service Hot Water Percent of Maximum Load			Schedule for Elevator Percent of Maximum Load		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	0	0	0	5	5	5	Off	Off	Off	2	2	2	0	0	0
2 (1-2 am)	0	0	0	5	5	5	Off	Off	Off	2	2	2	0	0	0
3 (2-3 am)	0	0	0	5	5	5	Off	Off	Off	2	2	2	0	0	0
4 (3-4 am)	0	0	0	5	5	5	Off	Off	Off	2	2	2	0	0	0
5 (4-5 am)	0	0	0	5	5	5	Off	Off	Off	5	2	2	0	0	0
6 (5-6 am)	0	0	0	5	5	5	Off	Off	Off	7	2	2	0	0	0
7 (6-7 am)	0	0	0	5	5	5	Off	Off	Off	7	2	2	0	0	0
8 (7-8 am)	15	0	0	40	5	5	On	Off	Off	10	2	2	0	0	0
9 (8-9 am)	70	20	0	70	8	5	On	On	Off	30	6	2	0	0	0
10 (9-10 am)	90	20	0	90	24	5	On	On	Off	36	12	2	0	0	0
11 (10-11 am)	90	20	0	90	24	5	On	On	Off	36	12	2	30	0	0
12 (11-12 pm)	90	20	0	90	24	5	On	On	Off	46	17	2	0	0	0
13 (12-1 pm)	50	10	0	80	5	5	On	On	Off	57	4	4	0	0	0
14 (1-2 pm)	85	10	0	90	5	5	On	On	Off	43	4	4	0	0	0
15 (2-3 pm)	85	10	0	90	5	5	On	On	Off	38	2	2	0	0	0
16 (3-4 pm)	85	10	0	90	5	5	On	On	Off	40	2	2	40	0	0
17 (4-5 pm)	20	0	0	90	5	5	On	Off	Off	30	2	2	0	0	0
18 (5-6 pm)	0	0	0	30	5	5	Off	Off	Off	18	2	2	0	0	0
19 (6-7 pm)	0	0	0	5	5	5	Off	Off	Off	3	2	2	0	0	0
20 (7-8 pm)	0	0	0	5	5	5	Off	Off	Off	3	2	2	0	0	0
21 (8-9 pm)	0	0	0	5	5	5	Off	Off	Off	3	2	2	0	0	0
22 (9-10 pm)	0	0	0	5	5	5	Off	Off	Off	3	2	2	0	0	0
23 (10-11 pm)	0	0	0	5	5	5	Off	Off	Off	3	2	2	0	0	0
24 (11-12 am)	0	0	0	5	5	5	Off	Off	Off	3	2	2	0	0	0
Total/Day	680	120	0	915	180	120	1000	800	0	429	91	52	70	0	0
Total/Week			35.20 hours			48.75 hours			58.00 hours			22.88 hours			3.50 hours
Total/Year			1835 hours			2542 hours			3024 hours			1193 hours			182 hours

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Table G-O—Laboratory Occupancy

Hour of Day (Time)	Schedule for Occupancy Percent of Maximum Load			Schedule for Lighting Percent of Maximum Load			Schedule for HVAC System			Schedule for Fume Hoods Percent of Maximum Load			Schedule for Equipment Percent of Maximum Load Typical Use			Schedule for Equipment Percent of Maximum Load High- Use		
	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun	Wk	Sat	Sun
1 (12-1 am)	5	5	5	20	10	10	On	On	On	53	53	53	20	20	20	100	100	100
2 (1-2 am)	5	5	5	20	10	10	On	On	On	53	53	53	20	20	20	100	100	100
3 (2-3 am)	5	5	5	20	10	10	On	On	On	53	53	53	20	20	20	100	100	100
4 (3-4 am)	5	5	5	20	10	10	On	On	On	53	53	53	20	20	20	100	100	100
5 (4-5 am)	5	5	5	20	10	10	On	On	On	53	53	53	20	20	20	100	100	100
6 (5-6 am)	5	5	5	20	10	10	On	On	On	53	53	53	20	20	20	100	100	100
7 (6-7 am)	5	5	5	30	10	10	On	On	On	53	53	53	20	30	30	100	100	100
8 (7-8 am)	10	10	10	50	10	10	On	On	On	55	55	55	30	30	30	100	100	100
9 (8-9 am)	20	10	10	90	40	40	On	On	On	60	55	55	40	40	40	100	100	100
10 (9-10 am)	90	30	30	90	40	40	On	On	On	98	65	65	50	40	40	100	100	100
11 (10-11 am)	90	30	30	90	40	40	On	On	On	98	65	65	50	40	40	100	100	100
12 (11-12 pm)	45	30	30	90	40	40	On	On	On	98	65	65	50	40	40	100	100	100
13 (12-1 pm)	45	30	30	80	20	20	On	On	On	73	65	65	40	30	30	100	100	100
14 (1-2 pm)	90	10	10	90	20	20	On	On	On	98	55	55	50	30	30	100	100	100
15 (2-3 pm)	90	10	10	90	20	20	On	On	On	98	55	55	50	30	30	100	100	100
16 (3-4 pm)	90	10	10	90	20	20	On	On	On	98	55	55	50	30	30	100	100	100
17 (4-5 pm)	90	10	10	90	20	20	On	On	On	98	55	55	50	30	30	100	100	100
18 (5-6 pm)	90	10	10	90	10	10	On	On	On	65	55	55	40	20	20	100	100	100
19 (6-7 pm)	30	5	5	50	10	10	On	On	On	55	53	53	30	20	20	100	100	100
20 (7-8 pm)	10	5	5	50	10	10	On	On	On	55	53	53	30	20	20	100	100	100
21 (8-9 pm)	10	5	5	30	10	10	On	On	On	53	53	53	20	20	20	100	100	100
22 (9-10 pm)	10	5	5	30	10	10	On	On	On	53	53	53	20	20	20	100	100	100
23 (10-11 pm)	5	5	5	20	10	10	On	On	On	53	53	53	20	20	20	100	100	100
24 (11-12 am)	5	5	5	20	10	10	On	On	On	53	53	53	20	20	20	100	100	100
Total/Day	855	255	255	1290	410	410	2400	2400	2400	1632	1334	1334	780	630		2400	2400	2400
Total/Week		47.85 hours			72.70 hours			168.00			108.28 hours			51.60 hours			168.00	
Total/Year		2495 hours			3791 hours			8760 hours			5646 hours			2691 hours			8760 hours	

Wk = Weekday

Schedules for occupancy, lighting, receptacle, HVAC system, and service hot water are from ASHRAE Standard 90.1-1989 and addendums, except that 5% emergency lighting has been added for all off hours. Elevator schedules, except for restaurants, are from the U.S. Department of Energy Standard Evaluation Techniques except changed to 0% when occupancy is 0%. These values may be used only if actual schedules are not known.

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Compliance Form

The following pages provide a sample performance rating report that conforms to the requirements of the rating method. A modifiable electronic version is included on the CD that accompanied this Manual, and is also available for free download from the ASHRAE website.

This form is intended for use with the performance rating method when a rating shell is not used. If a rating shell is used, it should automatically generate a version of the rating report. If this form is used instead, the user should fill in the form using information taken from the output reports of the simulation program.

In addition to this form, the user should submit completed forms from the other chapters of this Manual. Those forms document the proposed design and its features, and they also make it clear where the proposed design under the rating method differs from the prescriptive requirements. Finally, as noted at the bottom of this form, the user should provide a list that describes all instances where input assumptions differ between the baseline building and proposed design runs.

The Performance Rating report has several sections designed to make clear to the rating personnel what the building characteristics are and how the rating method has been applied to it.

Project Name and Information

This section begins with a basic statement that the project complies with the mandatory requirements of the Standard, and notes the date of the plans upon which the performance rating runs are based. This section also records basic information about the project, the people involved, the heating fuel, and the weather data used for the rating analysis. There is also space to summarize the areas and uses within the building.

Advisory Messages

This section reports information from the simulation runs that is helpful in identifying modeling problems or special situations.

Performance Rating Result

This final section is prepared by the person responsible for the building performance rating submittal to the rating authority.

Energy Use and Energy Cost Summary

These sections summarize the energy use breakouts by end use and by fuel type. They also show the percent difference between the proposed and the baseline buildings. When the percentage value is less than 100%, then the proposed design is better than the baseline.

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Performance Rating Report

Project Name:	
Project Address:	Date:
Designer of Record:	Telephone:
Contact Person:	Telephone:
City:	Principal Heating Source: ☐ Fossil Fuel ☐ Electricity ☐ Fossil/Electric Hybrid & Purchased Heat ☐ Other

Space Summary

Building Use	Conditioned Area (ft²)	Unconditioned Area (ft²)	Total Area (ft²)
Total			

Advisory Messages

	Proposed Building Design	Baseline Building	Difference Proposed – Baseline
Number of hours heating loads not met (system/plant)			
Number of hours cooling loads not met (system/plant)			
Number of warnings			
Number of errors			
Number of defaults overridden			

Simulation General

	Proposed Building Design	Baseline Building	Baseline same as Proposed?
Simulation program			
Weather data			
Utility rates			

Performance Rating Result

The proposed and baseline buildings comply with the mandatory requirements of the ANSI/ASHRAE/IESNA 90.1-2007 Standard and meet the Performance Rating Method requirement. Individual certifying authenticity of the data provided in this analysis:

Signature:	Title:

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Project Name:	
Contact Person:	Telephone:

Energy Summary by End Use

End Use	Energy Type	Proposed Building		Baseline Building		Proposed / Baseline Energy (%)
		Energy (10^6 Btu/yr)	Peak (10^3 Btu/h)	Energy (10^6 Btu/yr)	Peak (10^3 Btu/h)	
Lighting - conditioned						
Lighting - unconditioned						
Space heating (1)						
Space heating (2)						
Space cooling						
Pumps						
Heat rejection						
Fans - interior ventilation						
Fans - interior exhaust						
Fans - parking garage						
Service water heating						
Office equipment						
Elevators & escalators						
Refrigeration (food, etc.)						
Cooking (commercial)						
Total Building Consumption						

Energy Summary by End Use

	Proposed Building		Baseline Building		Percentage Improvement
	Energy Use (10^6 Btu/yr)	Energy Cost ($/yr)	Energy Use (10^6 Btu/yr)	Energy Cost ($/yr)	100 x (1 – Proposed Energy Cost/ Baseline Energy Cost) %
Electricity					
Natural gas					
Other fossil fuel					
District steam					
Total Nonsolar					
Solar or site recovered					
Total Including Solar					

* These results use assumptions for showing compliance during a typical year; actual energy costs may be substantially different.

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ERRATA SHEET FOR THE USER'S MANUAL TO ANSI/ASHRAE/IESNA STANDARD 90.1-2007 ENERGY STANDARD FOR BUILDINGS EXCEPT LOW-RISE RESIDENTIAL BUILDINGS

October 29, 2008

The corrections listed in this errata sheet apply to all copies of the ANSI/ASHRAE/IESNA Standard 90.1-2007 User's Manual, identified on the outside back cover as "90353 PC 8/08" for the first printing. The shaded item has been added since the previously published errata sheet dated August 21, 2008 was distributed.

Page	Erratum
5-34	**Example 5-L - Prescriptive Building Envelope Option, Tucson Supermarket.** In the fifth sentence of the second paragraph of answer "A" change "Exception (c) to § 5.4.4.4.1" to Exception (c) to § 5.5.4.4.1".
7-17	**Service Water Heating Compliance Documentation (Compliance Form).** In the Combination Space and Water Heating Worksheet (§7.5.1), third and fourth columns, change "≤" (less than or equal to) to "<" (less than) in five places in each of the two columns column.

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